Vol. XXXVII. JUNE, 1897.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

THE SUBSTITUTION OF ELECTRICITY FOR STEAM AS A MOTIVE POWER FOR SUBURBAN TRAFFIC.

No. 803.

By JOHN FINDLEY WALLACE, M. Am. Soc. C. E.

PRESENTED FEBRUARY 3D, 1897.

WITH DISCUSSION.

It is not the intention of the author in this paper to treat exhaustively of the question of the substitution of electricity for steam in the handling of heavy suburban traffic, but rather to give a concise statement of the history and results of certain investigations made by him, to the end that the *Transactions* of the American Society of Civil Engineers may contain a record of the progress which has been made in the use of electric motors for transportation purposes, and to lay the foundation for future papers on this subject. The author does not pretend to any expert electrical knowledge, and requests an open criticism of any remarks made herein by experts in this branch of engineering.

In December, 1891, the author was called upon by the management of the Illinois Central Railroad to examine into and report upon the

practicability of transporting large numbers of passengers between Van Buren Street, in the city of Chicago, and the grounds of the World's Columbian Exposition. As it would not be economical to establish a special service for the short exposition period which could not be utilized thereafter, the question of substituting electricity for steam as a motive power to handle the regular suburban business of the Illinois Central Railroad was a necessary sequel to the original proposition. An examination was made of the principal electric street lines in various cities of the United States. At that date none of the railroad lines that were originally steam roads had adopted electricity as a substitute for steam. So far the application of electricity for transportation purposes in the United States had mainly been confined to its substitution for horse-power on street railway lines and in the establishment of new lines of this character, in which the units of transportation were necessarily small and were moved at frequent intervals through short distances. The problem naturally divided itself into three divisions:

First. Practicability.—(*a*) As to the possibility of carrying 10 000, 20 000 or 30 000 passengers per hour between the World's Fair site and Van Buren Street, in Chicago, by electricity. (*b*) The practicability, after the close of the World's Fair in 1893, of satisfactorily handling the suburban business of the Illinois Central Railroad by electric power.

Second. Economy.—(*a*) The cost of handling the World's Fair business between the Lake Front Park and the site of the Exposition by electricity, as compared with steam. (*b*) The cost of operating the suburban traffic of the Illinois Central Railroad by electricity instead of steam after 1893.

Third. Appliances.—(*a*) Line construction. (*b*) Power plant. (*c*) Motors and cars.

Granting that the application was practicable, the next question to be considered was economy. Should it be shown that it would be economical, the third question to be considered was the nature of the appliances to be used.

In order to secure the necessary data for an intelligent consideration of these problems, the prominent electric manufacturing companies in the country were asked to submit in writing their answers to a list of questions. As it is, of course, not advisable to disclose the

names of the companies giving the information contained herein, they will be designated as (*a*), (*b*), (*c*), (*d*) and (*e*). Following is a statement of the requirements and the questions submitted to each company, with their answers in regular rotation:

"In considering the question of passenger transportation facilities between the Lake Front Park, in the city of Chicago, and the Columbian Exposition in Jackson Park, it is desirable to know whether electric power can be applied for passenger service with economy. The following are the physical conditions:

"The track will be first-class standard gauge railroad track, and the maximum grade will not exceed one-half of 1 per cent. The distance between the terminal stations will be 7½ miles. Between these stations there will be practically no curvature. If possible, loops will be constructed at each end of the line, with a radius of about 300 ft. As a basis for the consideration of the question, it is estimated that trains should consist of one motor car and two trailers, with provisions for carrying 336 passengers. The dimensions of the motors and trailers would be from 36 to 40 ft. in length, with cross-seats, and the cars should be about 8 ft. wide in the clear on the inside. It has been estimated that these cars will weigh about 20 tons, loaded. It is desired that the speed should be about 20 miles per hour. It is estimated that the equipment required will be from 60 to 70 motors and from 120 to 140 trailers. Estimating that 112 passengers can be carried in each one of the cars, including the motor, each train would carry, as stated above, 336 passengers. Assuming that one train can be loaded and despatched from the terminal station each minute, the capacity per hour will be 20 160 passengers.

"Considering the above conditions and assumptions, in order to determine the advisability of adopting electric power, answers to the following questions are desired:"

Question 1.—What capacity should motors have in horse-power?

Answers.—(*a*) Capacity of motors, 75 H.-P. each, two on each axle.

(*b*) A 20-ft. motor car and two 40-ft. trail cars, as specified, could be operated at less than 75 H.-P. on an average, but the maximum required at starting, on grade and curve work, and with specially heavy loads, might raise these figures 50 to 75 per cent. It is, therefore, desirable to have, at least, two 75-H.-P. motors, one on each axle of the motor truck, and it is quite possible with the space at disposal to make these 100-H.-P. motors, that would be able to draw three or possibly four trail cars heavily loaded.

(*c*) The motor cars should have a capacity of 100 H.-P. each, but should be capable of developing up to 200 H.-P. for short periods of time without harm or injury to any part. The best way to attain this result will be to employ two Eickemeyer-Field electric motors

of 50 H.-P. each, one motor on each four-wheel swivel truck of the motor car.

(*d*) To handle a train of four cars, each weighing, when loaded, 25 tons, will require a draw-bar pull of nearly 1 000 lbs. This will mean a continuous development of about 50 H.-P. on the axle, and occasionally much greater power for acceleration, etc. We should, therefore, recommend four of our standard 25-H.-P. motors wound for 25 miles an hour. These will weigh each 2 500 lbs., approximately, so that four of them will add a weight of 5 tons to the train.

(*e*) Taking various measurements made on electric tramcars as a standard of comparison, 200 H.-P. will be required to satisfactorily operate a 75-ton train, making an average speed of 20 miles per hour.

Question 2.—What will these motors cost? In giving cost, separate the cost of motors and motor cars.

Answers.—(*a*) Cost of two motors, $5 000, with all regulating devices. Approximate cost of trucks, $3 000, making cost of electric locomotive $8 000.

(*b*) The motor car, body and trucks, without electrical equipment, will cost in the neighborhood of $1 500 to $1 750, depending on weight and finish. The motors would cost roughly $40 per horse-power, to which should be added about $400 per motor car for controlling mechanism, electrical appliances, wiring, labor, etc. Thus, a 150-H.-P. motor car would cost complete about $8 000, although these figures would be somewhat reduced in an actual bid.

(*c*) The Eickemeyer-Field motors will cost about $6 000 for each motor car. This figure includes trucks and ordinary brakes, but does not include air-brake apparatus. The cost of the car bodies will be approximately $4 500 each additional, making the cost of the motor cars, without air-brake apparatus, $10 500 each.

(*d*) The four motors, together with their controlling apparatus, contact trolleys and all other devices necessary to completely equip the car, will cost $5 000 per motor car. The cars themselves we should estimate at $2 000 apiece.

(*e*) No answer.

Question 3.—Give approximate cost of trailers. Cars to be open cars, with cross seats, on first-class double trucks.

Answers.—(*a*) Trailers to be furnished by the Illinois Central Railroad. Cost, about $3 000 each.

(*b*) We cannot at this moment make more than an approximate bid upon the cost of trail cars, as so much depends upon weight, style and finish. The cost would not exceed, however, $2 000, and would probably be a little less.

(*c*) The approximate cost of open trailers with cross-seats on first-class four-wheel double trucks is $3 500 each, with ordinary brakes.

(*d*) The trailers we should estimate at $2 000 apiece, which ought to furnish a car serviceable, not only for the World's Fair, but for suburban service afterwards.

(*e*) No answer.

Question 4.—Is it desirable to have horse-power used for motor cars consolidated in one unit or divided into two?

Answers.—(*a*) It is desirable to equip each electric locomotive with two motors.

(*b*) There should be two motors for each motor car. In case one is disabled, the other would be in condition to pull the train in and clear the road without difficulty.

(*c*) It is desirable to have the power divided equally between the two trucks, and applied equally on all the wheels of both trucks, since by this means traction on all wheels will be secured, and in the event of one motor giving out, the other will run the train to the terminal. The motor car can be arranged to drive from either end, the driver's box being placed on one side of the center line of the car, so as to leave the usual free passage from car to car.

(*d*) It will be most desirable to have the motor power divided into two or four parts. The four-part division will give the most efficient means of control, speed and power. This will enable the use of the series-multiple controlling switch, whereby the motors can all be started in series for slow speed and then changed over to multiple series for intermediate speed, and finally thrown into multiple for high speed. A still further adjustment could be made by commuting the fields so that four different speeds, varying from 5 miles to 25 miles an hour, could be obtained with maximum efficiency, and without the efficiency dropping materially at intermediate speeds.

(*e*) With motor cars it is desirable that the horse-power should be divided into two units, the reason being that, in the case of the failure of one motor, the train is not completely disabled. Further, motors of 100 H.-P. would be more satisfactory electrically for varying loads, where the motors are not accessible to the operator. In the present case it is thought advisable to run these two motors in series, so that the electro-motive force on the line can be increased to 1 000 volts. With this electro-motive force, but one-fourth of the weight of copper will be required to transmit the same power as with 500 volts.

Question 5.—What is the best method to transmit the power of the motor to the axle, by gear or by crank?

Answers.—(*a*) The best method of transmitting the power of the motor to the axle is by placing the armature directly upon the axle, or transmitting it by steel gears.

(*b*) No form of gear or crank transmission should be considered for a moment in work of this character. The armatures should be radial on the axle, and the motors of the utmost simplicity in con-

struction. It is estimated that 75% of the expense of maintaining geared motors is due to the gear in one form or another, not only by direct breakage of gearing, involving the necessity of replacement, but also by armature and field burnouts, due to "locked gearing" or other electrical difficulties, caused by broken parts getting into the revolving parts of the motors. Moreover, there is a constant and heavy drain upon the power station, caused by friction of gearing, which amounts even in comparatively low-speed work to at least 20% of the total power consumption. It is safe to say that motor gearing up to the present time has cost railway companies at least 1¼ cents per car mile on an average. Gearless motors for ordinary street car work have been designed and are now in regular operation at speeds slower than most of the new types of single-reduction motors, and with very high economy in power consumption and cost of maintenance. It is, of course, a much simpler problem to design gearless motors of larger power to run at higher speed and with a greater space at command obtained by the use of a 42-in. wheel instead of 30 and 33 ins. with which the street car gearless motor can be used. The gearless motor has many characteristics which give it great value in all classes of railway work. It starts from rest smoothly, attains speed quickly, and, having no gears to impede, it will bowl along over a smooth track at a cost for power much less than any geared motor. To fulfil your requirements, all that it would be necessary to do would be to increase the dimensions of the street-car motor, making a 33-in. armature instead of a 23-in., as at present, with fields and framework made to correspond. When it is stated that the power of an electric motor varies roughly as the cube of its armature diameter, all other things being increased proportionately, you will see what a simple problem it is to obtain the requisite horse-power in the way above suggested. In mounting these motors on the truck the armature will be keyed to a hollow shaft which will surround the car axle, leaving an annular space of at least 1½ ins. This hollow shaft will be carried in the frame work of the motor itself, hung on strong cross-girders of the truck through flexible rubber bushings of special design. The entire truck frame and motors will thus have an easy spring movement, which will prevent pounding on the track, breakage of wires, etc., which is always found in geared motors which are more or less rigidly attached to the framework. The armature is of the ring type, which permits of separate and independent coils, which may be rewound, in case of burnout, at nominal expense. This peculiar type of armature construction has been found by far the most satisfactory in street car practice, it being adopted by nearly every company. This company was the first to recommend its use, and the road operating it in Rochester, N. Y., is now making 250 000 car-miles per month, at a cost for repairs of less than ½ cent per car mile, although the motors are

of the double-reduction (four-gear) type. Further information upon the peculiarities of the gearless motor will be given verbally or upon request.

(*c*) The best method of transmitting the power of the motor to the axle is by cranks and parallel rods; this calls for a motor which turns its armature at the same speed of rotation as car axle. At first sight, this comparatively slow armature speed might appear objectionable, but it has been found easily possible in practice to so design and construct a motor that under these conditions it will surpass in commercial efficiency any form of motor as yet applied to work of this character. As bearing out our statement that cranks and parallel rods are the best means of connecting the motor to the axle, we have only to point to the engineering practice with steam locomotives for the past 40 years. Again, in mine hoisting machinery, gearing has been almost entirely abandoned, the engines being connected directly to the cable drum.

(*d*) In case only 25 miles an hour is desired, the best method would be by the use of spur gearing—gearing the armature directly to the axle. This will enable the use of standard motors of light weight and render repairs easy. The gears, being single reduction and run in oil, will be practically noiseless, and the wear and tear will be very slight.

(*e*) The best method of transmitting the power to the axle which we are familiar with is the spur gear. Cranks have been used from time to time for this purpose, but the information we have gathered on this subject has not been favorable to the use of these cranks.

Question 6.—What parts of motors are liable to give the most trouble from breakages, and what is the best and quickest method of handling motors that are disabled out on the line, and to avoid the least delays to traffic?

Answers.—(*a*) By using best standard motors there will be no trouble from breakage. In case one motor should be disabled electrically, the train may be run into the terminal station with the other motor and then be repaired.

(*b*) The most trouble from breakage is experienced with gears, which is obviated in the motor described in Answer 5. There is also some liability to burn out armature and field coils in electric motors, if heavily overloaded; but with the type of motor referred to, these burnouts are of very rare occurrence, because of the independence of the armature coils and the fact that they are thoroughly ventilated. Moreover, the burnout of more than one coil at a time is a very rare occurrence, and the motor will do work and help to carry the train through to the terminus, even if several coils are burned out, a very important feature. However, in general plan outlined as above, there is ample power in one motor to draw a train in, so that complete stalling of the train on the road would be very rarely experienced.

(*c*) The parts of motors most liable to give trouble by breakage are the armature and the commutator. This is not saying that these parts are very liable to give trouble, but simply that they are the most liable. The best and quickest way of handling motors that become disabled out on the line is, in case both motors are disabled, to push the train in by the next motor coming along, which, owing to its allowance for development of extra power, should do the work without injury to it. In case but one motor of the car should be disabled, the remaining motor would run the train to the terminus, where it could be exchanged for one of the reserve motors. In the event of such damage to a motor that its shaft would not revolve, the connecting rods could be quickly removed, and the wheels and axles would then serve as an ordinary truck.

(*d*) The parts of the motor most liable to require repairs are the bearings and gears, but these have been so perfected in the last year that their maintenance is about as small as any piece of mechanism could be expected to be. Duplicate trolley wires, duplicate trolleys, duplicate motors and proper cut-out switches will enable a motor car disabled in any of its parts to complete its round trip in any conceivable case. Should, however, such a breakdown occur as cannot be foreseen, and the motor car be completely disabled, it would have to be pushed to the terminal station or to the nearest siding by the train in the rear, and the motors would have abundant power to handle two trains if necessary.

(*e*) With proper system of inspection, there is very small liability of the breaking of any part. The gears require replacing oftener than other parts, but a mechanic should be able to tell from the condition of the gears how much longer they are to be relied upon. The brushes on the commutator would require attention about as frequently as the journals. With proper care these very rarely cause trouble. In case a motor car becomes completely disabled, the best method of avoiding delay would be to side-track the train. One or two motor cars could be held in readiness along the line, so that no serious delay would be possible.

Question 7.—What is the best-known brake for electric cars and motors suitable to the requirements of this line?

Answers—(*a*) The best-known brake for electric railway trains is the Westinghouse air brake. The air pump can be operated by a small separate motor on the locomotive, and all the air-brake appliances will be practically the same as those now in use on steam roads.

(*b*) You should use a Westinghouse air brake of the usual description. We would place in the motor car a small electric motor, geared to an air pump, which would furnish the required power for working the brakes. You would thus have the best working power found in any system of street railway locomotion.

(*c*) The best brake for motor cars and trailers operated in a train, as required, is the air brake.

(*d*) A compression air brake would be the most reliable to use in connection with a system of this kind, the air pump to be operated by a separate electric motor on the motor car and controlled by the driver.

(*e*) The best brake for practice of this sort is the air brake.

Question 8.—What is the largest motor now manufactured, and where is it operated ?

Answers—(*a*) The largest motors which this company has constructed for suburban railway service are of 30-H.-P. capacity and are in operation in Sioux City, Ia.

(*b*) We have built 100-H.-P. motors for transmission of power purposes, and dynamos up to 500 H.-P., any of which could be used as motors of the same power on occasion. For railway work, the largest motors yet manufactured in this country are 30-H.-P. motors, which are being put out by the various electrical manufacturing companies, ourselves among the number. In England, the London and South Western Company is using large motors of the gearless type for the operation of their cars under ground, these cars being, as we understand, of the long double-truck type, similar to those which you will require.

(*c*) The largest motors of the type recommended, now in use, are of 30 H.-P., and are capable of developing 50 H.-P. for short periods of time with higher efficiency, and without injury to any part of the motor. Those 30-H.-P. motors are in operation at Toledo, O. They are each mounted on a four-wheel truck of 4-ft. 8½-in. gauge, having a wheel base of 6 ft. The wheels are 26 ins. in diameter, and make 265 revolutions when the car is going 20 miles an hour, which speed is frequently attained. These motors, with trucks complete, weigh 4½ tons, and upon each is mounted a 16-ft. street car body, weighing 3 tons, making the total weight of the motor car complete, 7½ tons. Fifty passengers can be carried in one of these cars without straining or overloading the motor. Curves of 32-ft. radius are rounded without difficulty, and, owing to the small diameter of the drivers, the tendency to leave the track on curves is very slight. In Boston, a 40-ft. car propelled by two 20-H.-P. motors, each mounted on a four-wheel swivel truck, is in use, the motors and method of connection being the same as herein recommended.

(*d*) The largest motor in existence is the freight locomotive at Whitinsville, Mass., rated at 120 H.-P., but which has given an actual draw-bar pull of 10 000 lbs.

(*e*) The largest stationary motor in operation is the 100-K.-W. motor, manufactured by the Edison General Electric Company. This motor is in operation in the Schenectady works and in various other.

plants. The largest motor outfit with which we are familiar is the 60-H.-P. equipment manufactured by the Edison General Electric Company. This is in operation upon the Schenectady Street Railway and various other railways.

Question 9.—In using two motors on a car it was understood that the motors work separately on both forward and rear trucks, and that the motor cars do not have to be turned at end of line.

Answers.—(*a*) Using two motors on each locomotive, the train can be operated the same as with steam-power.

(*b*) See answer to Question 10, which is for Questions 9 and 10.

(*c*) The two motors, thus applied to the car, will each work independently of the other end upon its own truck. The motor cars can be driven from either end and in either direction.

(*d*) The four motors would all work in unison, but any one or more could be cut out and the other motors do the work. Motors can be run either way and reversed with a single switch. Each can be controlled from either end of the motor car, and the car can be treated in every respect as a double-ended locomotive.

(*e*) The statement made that the motors do not have to be turned at end of line is correct.

Question 10.—Can both motors be used at once in the same direction, and can motors be reversed on line in an opposite direction, and can both motors be operated from same end of car?

Answers.—(*a*) Both motors can be used at once in the same direction, and may be reversed on the line in an opposite direction, and both motors may be operated independently of each other. With one motor in operation, the speed of the train will be considerably less than 25 miles per hour.

(*b*) Both motors can be controlled from either end of the car to work together in either direction; in other words, you can do with them precisely what you can with a locomotive, and, in addition, you can never speak of the motor car as running backwards, as it is symmetrical in form.

(*c*) Both motors can be used at once in the same direction and can be reversed on line from either end of car. Both motors can, of course, be operated from same end of car.

(*d*) Unless a motor is disabled, all the motors will be used simultaneously, as this gives the most efficient service and least heating of motors.

(*e*) Both motors can be used at once in the same direction. The motors can be reversed on the line in an opposite direction, and both motors can be operated from the same end of the car. The above conditions are common to street railway practice.

Question 11.—If the motor is designed for a speed of 20 miles an hour, with a certain load, can the speed be increased with a less load

without overstraining the motor and without any change in the mechanism, and what percentage can speed be increased ?

Answers.—(*a*) The motors will be so designed that when hauling a load of 150 tons they will run at a speed of, say, 25 miles per hour, and with a less load they will run faster without overstraining and without any change in mechanism. The speed will increase nearly in direct proportion as the load decreases.

(*b*) The answer to this question depends upon the characteristic curves of the motor. In a general way, it may be said that we can design and build a gearless motor car which would operate about as follows : In starting a 70-ton train, it would take, perhaps, 125 E. H.-P. During the period of acceleration up to a speed of 20 miles per hour, the power would gradually fall from 125 H.-P. to, perhaps, 50 to 60 H.-P., or even less, the power exerted being required in overcoming friction of journals, etc. With a 50-ton train, the speed would, perhaps, reach 22 to 25 miles per hour, or a slightly greater speed than that of the 70-ton train, but it is a peculiarity of our special method of building motors than the speed under heavy loads does not fall greatly over that required for light loads; in other words, the motors "stand up to their work" on grades or heavy tractive pull. It may be said in passing that it would not be feasible to run a geared motor as rapidly as a gearless, since the liability of breakage would be much greater.

(*c*) Motor cars can readily be constructed so that while adapted for a speed of 20 miles an hour, with a certain load, their speed may be increased to 25 or 30 miles an hour with less load. The speed may even be increased with the same load without overstraining the motor and without a change in the mechanism.

(*d*) The motors designed to run 20 to 25 miles an hour would not be able to go over 35 miles an hour on the level with a light load.

(*e*) If the motor is designed for a speed of 20 miles an hour with a certain load, the speed can be increased with a less load without straining the motors and without any change in the mechanism. It is safe to say the speed can be increased 50% and not exceed the ordinary conditions of good practice.

Question 12.—In how short a distance can trains described above be brought to a stop with existing brakes from a speed of 20 miles per hour?

Answers.—(*a*) The train may be brought to a standstill by the Westinghouse air brake in about 100 ft.

(*b*) With air brakes only, as described, the result would be the same with electric traction as with steam. There is, however, an additional safeguard in an electric locomotive not possessed to the same degree by a steam locomotive. The motors may be instantly reversed by turning the controlling handle in such a way as to actually turn the wheels backward while the train is going forward, thus accomplish-

ing an extremely quick stop. This, however, is to be applied only in the most extremely urgent necessity, as the results are apt to be disastrous from the enormous amount of power necessarily going through the motor. In ordinary service an 80-ton train can probably be stopped within 400 to 500 ft.

(*c*) With air brakes a train of three cars can be stopped, under ordinary conditions of rail service, from a speed of 20 miles an hour within a distance of 350 ft. without excessive jarring.

(*d*) The theoretical distance for stopping a train going at 20 miles an hour would be about 80 ft., but it would not be safe to count on less than 120 ft. under the most favorable conditions, since the driver cannot always gauge his braking power to his load. Taking in all kinds of conditions and distances, all of 200 ft. should be allowed for stopping from a speed of 20 miles an hour.

(*e*) If brakes are put on each car, and the described conditions indicate that they should be, the train moving 20 miles an hour can be stopped in a distance of 200 ft., with ordinary conditions of track.

Question 13.—Upon the line under consideration, what would be the best location for the power house, taking into consideration that after the World's Fair the line will be extended 7 miles south and that trains will have to stop at suburban stations at intervals of ½ mile?

Answers.—(*a*) The best location for the power station will be the center of the line.

(*b*) The best location for the power house is always as near as possible to the center of the road which it is to serve. Other considerations, however, frequently come in to disturb the best theoretical arrangement. It is important that coal should be delivered directly at the power house without cost of cartage, and, therefore, the station should be located near the railroad track. Moreover, in a plant of this size, it would be high economy to condense, and the question of obtaining a cheap water supply for this purpose should not be overlooked. It is impossible to state, therefore, without a comparative estimate of available sites, what would be the best location, but it may be said in general that in a 15-mile line you can safely work within a radius of 2 or 3 miles from the exact center.

(*c*) The best location for the power house, from considerations of economy in distribution of electrical energy and in cost of copper, would be at the middle of the length of the road; this is true whatever the amount of business or number of stops to be made. This is assuming that only one power house can be used. If the length of the road operated should be extended to 15 miles, with a very heavy traffic, it might become more economical to supply the electrical energy from two power houses than from one, but for a traffic extending over 7 or 8 miles, one power house, located at the middle of the road, would keep the cost within reasonable limits.

(*d*) The best location for the power house would be in the neighborhood of 3 miles from the city terminus, and as near to the middle of the line as possible. For subsequent extensions a suburban station would be built somewhere beyond Jackson Park. The stations would be so large that there would be no loss of economy in having two stations instead of one.

(*e*) It is not possible to give an exact answer to this question without knowing the exact value of real estate at various locations along the line; also, facilities for procuring coal. Neglecting these items, however, and taking into consideration the statements made to us that the traffic on this second 7 miles of track to be built after the World's Fair falls off with the distance from the terminus of the present contemplated road, we would say the station could be most advantageously situated within about 2 miles of the end from which the extension is to be made.

Question 14.—How much power plant would be required to operate from 60 to 70 trains of 65 to 70 tons each at a speed of 20 miles per hour?

Answers. (*a*) The power plant should have an aggregate generating capacity of, at least, 4 800 H.-P.

(*b*) You should plan for a power plant of 10 000 H.-P. to provide a sufficient margin for reserve and contingencies. Your average output should not exceed 6 000 H.-P., if you ran three car trains, but there will frequently be call for 7 500 H.-P. on special days when loads or conditions of track are severe.

(*c*) The power plant necessary to operate 60 to 70 trains at 20 miles an hour we estimate at 5 000 H.-P. capacity. This estimate is based on use of 1 000 watts electrical energy for each ton weight to be moved; practically, it would be found that with 60 trains running at 20 miles per hour the horse-power required at the house would fall below 4 000.

(*d*) To operate the above-described four-car train of 100 tons would require about 100 H.-P. in the engine, and, as 40 of these will be running at once, 4 000 H.-P. will be needed continuously during the hours of maximum travel; allowing a reserve of 20%, the total power required for the central station would be 5 000 H.-P.

(*e*) Basing our answer to this question on the present street railway practice, from 12 000 to 15 000 H.-P. will be required to operate from 60 to 70 trains of from 65 to 70 tons at a speed of 20 miles an hour. It is possible that in the present case less power would be required, owing to favorable conditions of track and the small number of stops to be made. We do not feel safe, however, in stating that a less power would be required until we have had an opportunity to make a thorough investigation of the whole matter.

Question 15.—What excess power will be required in such a plant, if any?

Answers.—(*a*) It is advisable that spare machinery of at least 8 000 H.-P. generating capacity be added.

(*b*) You will see from Answer 14 that we allow 25% reserve.

(*c*) No excess of power above 5 000 H.-P. would be required, provided the power units were not too large.

(*d*) Twenty per cent. reserve would be sufficient, provided the station is carefully installed and the apparatus of liberal capacity.

(*e*) In a plant of the present description it seems unnecessary that more than a 20% margin should be allowed. In street railway practice larger margins are generally allowed, but the demands for power in this case are liable to fluctuate very greatly, while in the present case the demand for power is nearly constant.

Question 16.—What would you recommend as to the proper units into which this power should be divided?

Answers.—(*a*) The smallest unit into which it would be advisable to divide this power would be 800 H.-P.

(*b*) We would recommend 1 000-H.-P. engine units and 500-H.-P. dynamo units, two dynamos being coupled direct to the shafts of each engine.

(*c*) We would recommend the division of power into twelve engines of 400 H.-P. each.

(*d*) The units could be either ten of 500 H.-P. each, or five of 1 000 H.-P. each. The former would give greater flexibility, and the latter greater simplicity. It would be a matter that should be decided largely by prices of engines and similar considerations that would come up during the further discussion of the problem.

(*e*) We would recommend as the proper unit of power for the above work 1 500-H.-P. engines and 750-H.-P. dynamos, two dynamos to each engine, the engines to be triple compound condensing, with Corliss valves.

Question 17.—If the requirements for power should be reduced 50% after the World's Fair, what power of each unit would you recommend?

Answers.—(*a*) Answer contained in Answer 16.

(*b*) The same as indicated in Answer 16.

(*c*) If the power plant should be reduced 50% after the World's Fair, we would still recommend the same units of 400 H.-P.

(*d*) In case the power plant was to be materially reduced, the smaller unit of 500 H.-P. would be preferable.

(*e*) We would recommend the same type of machine, if the power should be reduced 50% after the World's Fair.

Question 18.—How many square feet in space will be required for the erection of steam and electric power plant, including boiler house?

Answers.—(*a*) The number of square feet required for the erection of the steam and electric plant, including the boiler house, will be 75 000.

(*b*) You will require a lot of about 350 ft. by 125 ft., or the equivalent in area, in case you can purchase land cheaply; otherwise, it is possible to arrange a two-story building, with a little more than one-half this space.

(*c*) We estimate the space required in square feet for the erection of steam and electric power plant, including boiler houses, at from 15 000 to 25 000, according to types of boilers, engines and generators used, with everything on one floor; if two floors are used, the space required can be reduced to about 12 000 sq. ft., or even somewhat less, if necessary.

(*d*) The boilers will require 2½ sq. ft. per horse-power, or, say, a building 145 x 85 ft., and the engines and dynamos will require 2.61 sq. ft. per horse-power, or, say, a building 145 x 90 ft; so that a building 145 x 175 ft. would be sufficient for the whole power plant.

(*e*) About 27 000 sq. ft. will be required for the erection of steam and power plant, including boiler-house, and a room about 130 x 130 ft. for engines and dynamos, pumps, etc., and a room about 80 x 130 ft. for boilers. We would recommend two separate smokestacks, one on each side of the room.

Question 19.—Give your opinion as to the most economical and best kind of boilers, engines and generators to use for such a plant.

Answers. (*a*) In our opinion, the most economical and best boilers are the Babcock & Wilcox; engines, of the Corliss type, and generators, manufactured by the Westinghouse Electric Company.

(*b*) We would recommend large water-tube boilers with mechanical stokers; a high grade Corliss type of engine and slow-speed generators adapted for direct coupling to the engine shafts. It is unsafe to experiment with new or unusual types of boilers or engines, and nothing but what have been found in the past to be the most reliable under all conditions should be thought of.

(*c*) A water-tube boiler of Babcock & Wilcox or similar design we should consider most economical and best suited to your requirements. For engines, compound condensing, medium-speed engines, directly connected to generator, will give economical results, provided water for condensing can be obtained with little cost. The obtaining of water would depend on the location of the plant. The generators should be of 400 H.-P. each and operated at a voltage of 500 to 600. They can be either of bipolar or multipolar construction and should have a commercial efficiency of 80% or over when under full load.

(*d*) Babcock & Wilcox boilers should be preferred, and compound or triple-expansion engines of slow-speed type, with generators directly coupled to the same.

(*e*) We recommend the Climax type of boiler as the most efficient, economical and as requiring the least floor space. We recommend a vertical triple-compound condensing Corliss-gear engine, with

a sub-base plate or foundation box, on which would be erected the engines and generators, with two generators to each engine, one at either end of crank shaft, with armature coupled directly on the crank shaft. We recommend a multipolar type of generator.

Question 20.—Give approximate cost of power plant, to erect engines, boilers, generators, separately.

Answers. (*a*) The approximate cost of power plant, complete, ready to run, will be $475 000, not including real estate.

(*b*) The steam plant, complete, including engines, boilers, condensers, heaters and all accessory apparatus, together with piping, labor in erecting and everything necessary to make the plant ready for operation, will cost, in round numbers, $60 per horse-power. The electric plant, complete, including generators, switchboard, appliances, controlling apparatus and accessory apparatus, including labor in erecting and making ready for operation, would cost, in round figures, $40 per horse-power. The cost of the power station, complete, would therefore be, roughly, $1 000 000; this figure would easily cover also the cost of the building itself.

(*c*) We estimate the approximate cost of engines and boilers, erected, including necessary pumps and heaters, at $40 per horse-power. This would make a total cost of $200 000 for 3 000 H.-P. The cost of twelve generators erected would be $120 000.

(*d*) The power plant would cost $91 per horse-power, if constructed in a first-class manner. This figure will allow for slow-speed directly coupled dynamos and slow-speed compound engines of the most approved type, and boilers, furnaces, steam connections, pumps, condensers and economizers, all of the best and most reliable makes. It would also include the cost of building, for which an allowance of $10 per horse-power has been made. The dynamos have been estimated at $35 per horse-power and the steam plant at $46 per horse-power, and it is with the understanding that the plant is to be in every way ample and above actual rated capacity that the above figures are given.

(*e*) The approximate estimated cost of the twelve 1 500-H.-P. triple-compound engines, with two dynamos each, would be $1 000 000. The approximate estimated cost of the boilers would be $144 000, and the necessary piping, pumps, etc., to the amount of about $20 000 to $25 000.

Question 21.—Give estimated cost for operating power plant, with coal at $1 per ton.

Answers.—(*a*) We estimate that the cost of operating the power plant, with coal at $1 per ton, will be $60 000 per year, including all fuel, labor and repairs.

(*b*) It would be entirely safe to figure upon $30 per horse-power per year in a station of this size, operating for 18 hours a day. The cost of generating, therefore, 7 500 H.-P. would be $225 000 per year, which should cover all expenses.

(*c*) When running at full capacity, the cost of fuel per hour, with coal at $1 a ton, would be about $4. This gives 2 lbs. of coal per horse-power per hour. The expense for firemen, engineers, generator attendants, we estimate at about $4 per hour. This would allow ten firemen at $2 each per day; two engineers at $5 each per day; one head generator attendant at $5 per day, with two assistants at $2 50 each per day.

(*d*) In the following estimate the interest and depreciation are included so as to enable the railway company to make a ready comparison between the electrical system and the steam system. No account is taken of the maintenance of cars, trucks, roadbed, etc., as these are believed to be common to both systems, with a slight advantage in favor of electricity, because of its greater cleanliness and greater ease on the roadbed.

CENTRAL POWER STATION.

Capacity, 5 000 H.-P.; maximum duty, 4 000 H.-P.; reserve, 1 000 H.-P.

Initial Cost:	Total.	Per H.-P.
Boilers and Furnaces, 10 Babcock & Wilcox (500 H.-P. each)	$75 000	$15
Piping, pumps, heaters and all accessories	25 000	5
Engines; five compound condensing, 1 000 H.-P. each	100 000	20
Foundations	30 000	6
Steam plant complete	$230 000	46
Building	50 000	10
Dynamos 5 000 H.-P., each to be direct coupled compound wound and to develop 800 volts; with switchboard and all accessories	175 000	35
Power station complete ready to run	$455 000	$91

	Per day.	Per H.-P. hr.
Interest on power station, at 6% per annum, $27 300	$74 80	
Maintenance and Taxes, at 5%	62 30	
Operating Expenses:		
Coal, 48 000 H.-P.-hours per day, at $1 per net ton, and 3 lbs. per H.-P.-hour.	$72 00	$0.001500
Oil and waste	2 16	.000045
Engineers, 2 at $4	8 00	.000167
Oilers, 4 at $2	8 00	.000167
Firemen, 8 at $2	16 00	.000334
Dynamo men, 2 at $3	6 00	.000125
Superintendents, 2 at $6 and $10	16 00	.000334
Total wages	$54 00	

Total cost of operation for six hours maximum work, and twelve hours at 50%, 48 000 H.-P.-hours, and 480 train-hours, or 9 600 train-miles, or 38 400 car-miles per day	$265 19

Total operating expenses per H.-P.-hour	$0 00553
" " train-mile	.0276
" " car-mile	.0069
" " passenger-mile, assuming that the cars carry 50% of their seating capacity	.000123

Cost:

LINE.

7½ miles of center-pole construction, including four lines of trolley wire and insulated feeders, sufficient to give a maximum drop of 20%, all complete	$40 000 00
Block signal system for automatically stopping trains approaching within a given distance of preceding trains	12 000 00
	$52 000 00

	Per year.	Per day.
Interest at 6 per cent	$3 120 00	$8 54

Maintenance of Line:

One line foreman, at $2 50	$2 50	
Four line men, at $1 75	7 00	
Total wages	$9 50	
Supplies	1 00	
Total	$10 50	$10.50
Running expense of line per day		19.04
Running expense of line per train-mile		.002
Running expense of line per car-mile		.0005
Running expense of line per passenger-mile		.00000892

Cost:

MOTORS.

Complete electric equipment for 60 motor cars, each including four standard 25-H.-P. single reduction water-proof motors with controlling mechanism and all accessories, including the installing of the same at Chicago and wiring of motor cars, at $5 500 per motor car	$330 000

	Per year.	Per day.
Interest at 6 per cent.	$19 800 00	$54 36
Maintenance and taxes, 10 per cent.	33 000 00	90 41

Operating Expenses:

60 drivers, 12 hours per day, at $3.	$180.00	
Grease and waste	15.00	
Running expense per day		$339 77
" " per train-mile		.0354
" " per car-mile		.0088
" " per passenger-mile		.00016

Assuming average of 50% load.

Total Initial Cost:

Central power station	$455 000 00
Line	52 000 00
Motor equipment	330 000 00
Total	$837 000 00

Motive Power Running Expenses Per Day:

Central power station	$265 19
Line	19 04
Motors	339 77
Total	$624 00

Motive Power Running Expenses Per Train-Mile:

Central power station	$0.0276
Line	.0020
Motors	.0354
Total	$0.0650

Motive Power Running Expenses Per Car-Mile:

Central power station	$0.0069
Line	.0005
Motors	.0088
Total	$0.0162

Motive Power Running Expenses Per Passenger-Mile:

Central power station	$0.000123
Line	.000009
Motors	.000160
Total	$0.000292

(*e*) The estimated cost of operating power plant, with coal at $1 per ton, 12 hours per day, would be as follows:

Coal, 110 tons	$110 00
One chief engineer, at $6 per day	6 00
Four assistant engineers, at $4 50 per day	18 00
One chief electrician, at $3 50 per day	3 50
Eight oilers, at $1 50 per day	12 00
Eight wipers, at $1 25 per day	10 00
Eight dynamo tenders, at $1 50 per day	12 00
Twenty-four firemen, at $2 per day	48 00
Two water tenders, at $1 50 per day	3 00
Twelve coal wheelers, at $1 25 per day	15 00
Ten helpers, at $1 25 per day	12 50
Water, at 1½ cents per 1000 galls	90 00
Oil, waste, etc	80 00
Total	$420 00

Question 22.—Will an electrical engineer be required to superintend the operation of this plant, or will a mechanical engineer be able to do so?

Answers.—(*a*) For the operation of this plant a first-class mechanical engineer having experience in electric railroading, with an electrician for an assistant, will be required.

(*b*) You should engage for your service an engineer of the highest professional standing. He should have a special experience in mechanical engineering, with some knowledge of electricity. He should have as assistants a first-class mechanical engineer, to have charge of the steam plant for the power station; a good electrician, to take charge of dynamos and electrical power plant; a superintendent of motive power or master mechanic, to take charge of car and station repairs of all sorts; and a superintendent of construction, for the overhead wiring system.

(*c*) A competent and experienced mechanical engineer can soon acquire the additional knowledge necessary to fit him for the position of superintendent of this plant. No electrical engineer who did not combine a thorough knowledge of mechanical engineering would be competent to superintend this plant.

(*d*) An electrical engineer, who should also be a mechanical engineer, will be necessary to superintend the operation of the plant.

(*e*) There should be one engineer of each class, as named in estimate in Answer 21.

Question 23.—What is the best method of transmitting power from power house to motors?

Answers.—(*a*) The best method of transmitting power from the power house to the motors is by the overhead trolley system, which will cost $150 000, including poles and all necessary copper wire.

(*b*) The overhead trolley system.

(*c*) The best method of transmitting power from the power house to the motors is by the overhead trolley system with rail return.

(*d*) The overhead trolley wire is decidedly the preferable means for conveying current to the motors. It would be fed by feeders, which would also be overhead or placed in a conduit.

(*e*) We would recommend as the best method of transmitting power from power house to motors the overhead trolley system.

Question 24.—If by the use of conduit, give estimated cost. If by the three-rail system, give cost. If by the overhead trolley system, give cost.

Answers.—(*a*) Answer contained in Answer 23.

(*b*) We would advise a strong wooden-pole construction on account of cost and insulation. The cost of poles, trolley wire, brackets (for center pole construction, which would probably be the best, if the suburban tracks are side by side), line appliances, track wire and labor in erecting, would be not far from $2 500 to $3 000 per mile of double track. The cost of feed wire would be very large and could not be given without knowing the location of the power station. It will be, approximately, $15 000 to $20 000 per mile of double track for a railroad system 15 miles in length, with power station in the center, operating 50 trains, requiring 100 average horse-power each.

(*c*) We estimate the quantity of copper required for conductors at 500 000 lbs. for the overhead conductors, and 250 000 lbs. for the rail work. At 15 cents a pound for copper this would make $75 000 for the overhead work, and $37 500 for the rail work. Copper is at the present time selling at a little less than this, being lower than it has been for a number of years. The cost of construction and material other than copper for the single line of poles required between the two lines of rails we estimate at about $10 000.

(*d*) The cost of the trolley wire with center-pole construction, together with necessary feeders, cut-out switches, lightning arresters, and all of the necessary apparatus to operate the line efficiently and safely, would be $1 000 per running train. Assuming that 40 trains would be running, it would require $40 000 for line construction.

(*e*) The cost of this overhead system could not be determined until line has been laid out, as the extra service would call for special line material, the style of which could only be determined by taking into consideration all of the conditions to be met.

Question 25.—If the overhead trolley system is used, what is the best method for supporting wire, and how far should the supports be apart?

Answers.—(*a*) The best method of supporting the wires in this particular case is by bracket suspension, and poles should be not more than 125 ft. apart.

(*b*) As before stated, we would advise wooden poles, with side brackets, extending over the side of each track, placed about 100 ft. apart.

(*c*) With overhead trolley system, the best method of supporting wires is by posts set midway between the two lines of rails, these posts being provided with iron bracket arms, extending 18 or 20 ins. on each side of the posts, trolley wire to be supported by proper clamps from the extremities of the bracket arms. Poles should be fifty to the mile, which would bring them about 100 ft. apart.

(*d*) Wooden poles 100 ft. apart placed between the two tracks, with a cross-bar reaching out each way to the center of each track, from the ends of which arms the trolley wires are supported from insulators, would be the preferable method of construction.

(*e*) For the overhead trolley system we would recommend the center-pole construction as being the best for the system under consideration.

Question 26.—(1) What size should trolley wires be? (2) What size should feed wires be, and what distance apart should they feed into the trolley wire? (3) Give probable cost of repairs and maintenance of three systems.

Answers.—(*a*) (1) The trolley wires will be No. 00.

(2) The size of the feed wires to be determined after a more complete examination of the nature of the ground, and they should feed in the trolley wire ¼ mile apart.

(3) The overhead trolley system will require practically no outlay for repairs, if put up properly.

(*b*) (1) Trolley wires should be No. 00 or No. 000, B. & S. gauge.

(2) There would be a number of insulated feed wires not exceeding No. 0000 in size. They should feed into the trolley wire at intervals of not over 500 ft.

(3) The overhead system should be maintained at a cost for labor and material of less than 5% of the original cost per year.

(*c*) (1) Trolley wire should be ½ in. in diameter of hard-drawn copper.

(2) Parallel conductors connected to the trolley wires at every post, in circuit with the trolley wires, would be employed, these conductors varying in capacity, according to the current to be conveyed.

(3) The cost to maintain and keep in repair the system of overhead wires and poles would not be very heavy. If properly constructed in the first place, the annual expenditure for maintenance would be a smaller percentage of the cost than that of maintaining a single line of track on the railroad.

(*d*) No. 00 wires should be used for trolley wires and about 60 000 ft. of No. 0000 wires for feeders. They should feed in at sections corresponding with the signal blocks and should be controlled by switches at the central station and also at the line, so that the current could be cut off from any part of the line either automatically by the block signal or at the will of the officials of the road. To repair this overhead system would require a gang of five men; one at $2 50 per day, and four at $1 75, making a total of $9 50 for wages, and $1 for supplies per day, making a total of $10 50 per day for maintenance of line.

(*e*) The size and style of trolley wire will have to be determined after plant is laid out. It is probable that special means for making the trolley contact would have to be provided. Feed wires * * * should feed into the trolley wire about every 500 ft. This distance, however, will have to be determined with reference to the size and style of trolley conductor finally determined upon. We are unable to give cost of repairs on such an overhead system until all the details have been worked out. If properly put in, it should not exceed 3% of the first cost.

Question 27.—What percentage of extra equipment will be needed to provide for repairs?

Answers.—(*a*) We would advise that 10% of the regulating devices for the motors, armatures, field coils, commutators, brush holders, gears and trolleys and bearings be kept in stock for repairs.

(*b*) You would need about 25% in the power station to provide for repairs and contingencies of traffic, and you should provide about 10% reserve of car equipment for repairs only.

(*c*) Ten per cent. extra equipment would be sufficient to provide for repairs.

(*d*) There should be allowed an extra equipment of motors of 10% of the whole number, and it would be necessary to keep in stock about $2 000 worth of duplicate supplies in the shape of gears, brasses, armatures, etc.

(*e*) About 15% extra equipment will be required to provide for repairs. The percentage of extra equipment depends very largely upon the superintendence and care given the motor cars.

Question 28.—What will be necessary in the way of repair shop, plant and forces to repair motors?

Answers.—(*a*) A small repair shop, with the following tools will be required: One hydraulic wheel press for pressing wheels on end of the axles; one engine lathe large enough to take in armature axle for turning down commutator and for repairing armatures in general; four winding lathes for winding armatures, and one lathe for winding field coils, in case you decide to wind your own coils; one small engine lathe for making minor repairs to regulating devices and a few vises

for bench work. The repair shop should also have the necessary soldering tools for repair work. One complete blacksmith shop outfit, one line wagon and line tools, blocks, tackle, etc. Total number of men in repair shop, about six.

(*b*) If you adopt gearless motors and slow-speed generators with ring armatures, you will need a small machine shop, covering an area of perhaps 50 x 30 ft., equipped with a few lathes, two or three planers, a radial drill, etc. Your force would consist of a half-dozen winders, who need not be skilled workmen, four or five good mechanics and a foreman. Your stock would consist of brasses, Babbitt metal, commutators and commutator bars, and three or four sizes of copper wire. The above is on the supposition that the heavy machine repairs on engines, etc., will be done in your locomotive repair shops, and repairs on car bodies and trucks in your car shops.

(*c*) The repair shop will call for an outlay in tools and employment of forces of no more than that necessary for a steam equipment of the same capacity. It is probable that this item of expense will fall considerably below that of a steam plant in the course of several years' operation, but for a year or two it will be safe to place the two systems on a level in this particular.

(*d*) A machine shop for ten mechanics, with ten lathes, one drill and one blacksmith's equipment, would be necessary to keep the motors in repair. There will also be room for a car repair shop for ten motor cars. This will require a space of about 70 x 200 ft.

(*e*) The tools required for repair shop will be about as follows: One 30-in. lathe, one medium-size drill press, one press for pressing commutators off and on, one gear cutter, one milling machine, one complete blacksmith shop, one forge.

The necessary help would be about ten men, at $2 per day, and this repair shop could be looked after by the superintendent of the line, assisted by the chief electrician.

Question 29.—In considering the question of the advisability of running more cars of less weight and capacity, is it desirable to construct a separate electric locomotive carrying no passengers, or a separate motor room in each end of the car, with a limited passenger capacity between the two motors, for the purpose of having larger drive wheels? Or would you recommend the present style of motor? Give prices of the three different kinds of motors.

Answers.—(*a*) In our opinion, it is desirable to construct separate locomotives carrying no passengers. These locomotives to be equipped with two motors each. Diameter of driving wheels to be 42 ins.

(*b*) As before stated, it would not be difficult to build a motor car of the type specified to handle three instead of two double-truck trail cars, all heavily loaded. We would not advise building a separate electric locomotive which would carry no passengers, because of

the fact that the controlling mechanism in electric motor cars is simple, and requires very little room as compared with that of a steam locomotive. Moreover, by making the motor car carry passengers, the weight of the latter is available for traction, and, as this car would be a smoking car, it would nearly always be well filled. We have already indicated the price of passenger motor cars. The price of an electric locomotive would not be greatly different, but would be more, rather than less.

(*c*) We think that it would not be desirable to construct a separate electric locomotive, carrying no passengers, but that the motor car should constitute one of the three passenger cars. We think the advantages lie in favor of trains with three cars, including the motor car, of medium weight and capacity. Two or three trains could be loaded at the same time, and, when loaded, could get under way promptly. No room would be taken up in the motor cars by the motor mechanism, and this car body could be the same in construction and capacity as those of the trailers.

(*d*) We do not think anything would be gained by running more cars of less weight and capacity. The trains could not well be operated nearer together than one a minute, and four-car or five-car trains could be operated about as well on this headway as a two-car or three-car train. Should the line be eventually used for suburban service, with frequent stops, the number of cars per train would have to be reduced, probably to three, while the central station power would remain the same. This is to allow for the greater power required to accelerate after the frequent stops. We would not advise partitioning off part of the motor car, as the whole of it might be utilized for passengers, but there would have to be a vestibule for the driver, in case the cars had no platform. The wheels would be 36 ins. in diameter, so that they would not come within the car body. In regard to the alternative of the separate locomotive, there is to be said—such a motor to do this work would be our 16-ton locomotive * * * equipped with two gearless motors. The cost of this would be $12 000, and it would be able to make greater speed than the gear motor above referred to—40 miles an hour, if necessary. These motors have not yet been built, but are now in process of construction, and would probably operate the road as efficiently as the single-reduction motor. The chief difficulty would be in producing a new type of motor in time for the World's Fair, especially as such a great number of them would be required.

(*e*) We think that your experience in handling passengers should enable you to give a much more accurate estimate of these questions than we are able to make. We are in favor of using motor cars instead of electric locomotives, since in the case of the motor cars the weight of the passengers with the heavy car necessary to carry them is

available for traction. We would also recommend the present style of motor.

Question 30.—How much will it cost to operate this system per mile, per motor and per car, and also per passenger per mile?

Answers.—(*a*) The cost of operating forty 30-ton electric locomotives will be from 9 to 10 cents per mile per locomotive, including all labor and repairs.

(*b*) You can operate at about 12½ cents per car-mile, or 35 cents per train-mile. If the traffic to the World's Fair is as great as is anticipated, you can undoubtedly operate at from 2 to 2½ cents per passenger. We shall be pleased to give detailed and convincing estimates of the cost of operation, if desired, and at the proper time.

(*c*) To figure the cost per mile per motor and per car and also per passenger per mile would involve a considerable amount of calculation. We will make this calculation later and submit it when made.

(*d*) Answered in No. 21.

(*e*) We are unable to give an accurate answer to this question at this time. Various factors enter into this that require considerable time to consider.

Question 31.—Is there any electric line in operation similar to the one under consideration?

Answers.—(*a*) There is a similar line on a smaller scale equipped by the Westinghouse Company now in operation at Sioux City, Ia. On this line, however, the motor car carries passengers. The road has 4% to 5% grades, with sharp curves.

(*b*) Not precisely, but, as before stated, we are meeting conditions in service of street car work which vary only in slight degree from those under consideration.

(*c*) There is no electric line in operation similar to the one under consideration.

(*d*) The line running from Brooklyn to Coney Island operating trains of three cars at a speed of 15 to 20 miles per hour and carrying 250 passengers per train is the nearest approach to the conditions given at Chicago. The West End road in Boston, operating from 300 cars over about 100 miles of line, is also a comparable instance. The West End is now building two large stations, the larger of which will have a capacity of 27 000 H.-P. They are now operating on one circuit about 3 000 H.-P.

(*e*) We are not familiar with any electric line that is similar to the one under construction.

Question 32.—What is the longest line now operated, and the greatest number of cars that are operated with one motor?

Answers.—(*a*) The longest line now in operation with one motor car and three trailers is in Sioux City, Ia.

(*b*) One of the longest lines now operated is probably that between St. Paul and Minneapolis, a distance of about 25 miles; a speed of 20 to 25 miles per hour is attained on this road, we believe. One of the most severe conditions of operation that we know of is found at Jamestown, N. Y., whose street railway is operated by our motors. The motor cars have 18-ft. bodies, exclusive of platforms, which are vestibuled, making a car which weighs, with motors, between 6 and 7 tons, without loads. These cars are equipped with two 15-H.-P. double-reduction motors. The summer traffic is very heavy, and the motor cars draw in regular service one trail car, both heavily loaded, over a succession of grades reaching a maximum of 10% and having a number of sharp reverse curves therein. During the past summer there have been occasions when the railway company has been forced to draw three trail cars with one of these 30-H.-P. motor cars, making four in all, over some of the lighter grades of the road.

(*c*) There are many lines of electric cars, 8 miles in length, in operation at present, and two cars are frequently operated by a single motor car.

(*d*) Accompanying this paper is data sufficient to answer this question. (Answer 31.)

(*e*) The longest line with which we are familiar that is operated from one station is 13 miles in length. We believe there are longer lines, but in general they are operated from more than one station.

Question 33.—Give capacity per hour, speed and time between trains?

Answers.—(*a*) See page 158.

(*b*) We have no information with which to reply to this question.

(*c*) The electric lines now in operation are ordinary street car lines.

(*d*) The greatest traffic handled by an electric road with which we are familiar is the West End, which handles on its electric cars as many as 15 000 passengers per hour. The cars run on some parts of the line with less than 20 seconds headway and are often operated at a speed of 18 miles an hour.

(*e*) A train could be started every minute, and, supposing each train to carry 336 passengers, this would make about 20 000 passengers per hour. To do this, however, would necessitate the construction of three platforms from which passengers could enter cars at both sides at the same time. We would suggest that the train drop its passengers at one platform and then move forward to another platform where passengers could enter cars. By having three platforms from which trains would leave, it would give three minutes for a train to become loaded. The speed on the line could be arranged at anywhere between 20 to 25 miles an hour. The time between trains would be one minute. It would possibly be better to make the road four tracks wide with switches at every half mile, so that in case of accident to a

train the train following could be switched on to the other track for the same direction, and thus avoid delay. The road, of course, would have to be equipped with the block system, or something similar, so that "end on" collisions would be avoided.

Question 34.—Is it possible and practicable to carry from 20 000 to 30 000 passengers per hour with electric power under the conditions named?

Answers.—(*a*) There is not the slightest doubt but that 20 000 to 30 000 passengers can be carried from the Lake Front Park, in the city of Chicago, to the Columbian Exposition by electric power under the above conditions.

(*b*) Yes, without question.

(*c*) We think it possible and practicable to carry 20 000 passengers per hour, or more, from Lake Street to Jackson Park by electric power under the conditions named. First-class terminal facilities would need to be provided in order to reach the above figure.

(*d*) It is quite possible and practicable to carry 20 000 and, probably, 30 000 passengers per hour with the electric motors under the conditions named.

(*e*) The statements made in Answer 33 apply as well in this.

Question 35.—Is it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893?

Answers.—(*a*) It is possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893.

(*b*) Yes. We could install three such plants with our present factory facilities.

(*c*) We consider it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893.

(*d*) It is quite possible and practicable to have the plant in operation by March 1st, 1893, especially if standard motors are used and the contract given before April 1st, 1892.

(*e*) We think it possible and practical to supply the apparatus for this plant, ready for full and complete operation, by March 1st, 1893.

Question 36.—How soon will it be necessary to award the contract for the above plant in order to have the line ready for operation by March 1st, 1893?

Answers.—(*a*) It will be necessary to award the contract for the above plant on or before March 1st, 1892, in order to have it in operation by March 1st, 1893.

(*b*) The contract should be placed by March 1st, 1892, in order to be certain of completion at the specific time.

(*c*) In order to complete this plant by March 1st, 1893, contracts for the principal portions of the work should be made very soon.

(*d*) Before April 1st, 1892.

(*e*) It would be necessary to award the contract at the earliest possible date, not later than March 1st, 1892, since the apparatus should be put in operation by installments, and the various officers become familiar with their duties before the system is worked to its full capacity.

Question 37.—Would your company guarantee, on your own specifications and at an agreed price, the successful installation and operation of this plant by March 1st, 1893, with guaranteed capacity of 20 000 people per hour in one direction? (It is understood that whenever the capacity of 20 000 people per hour is mentioned, it is in one direction.)

Answers.—(*a*) Yes; provided you make the necessary arrangements to load the passengers on and off the cars.

(*b*) We would make such a guarantee under heavy penalties of non-fulfilment.

(*c*) In our opinion, the units above indicated. that is, an engine, with boilers and generator and one train of cars, could be placed in operation by June 1st, this year. This train could be operated over a sufficient length of your track to fully determine all questions of speed, power and capacity. Our company would probably be willing to undertake the construction of the electrical apparatus required within the time specified, conditioned on the approval of the operation of the single train, above mentioned, at as early a date as practicable. Our preference would be not to have the responsibility of the contract for the steam plant, nor for the erection of the conducting wires; there are parties who make this line of work specialties, and if we were called upon to assume the whole contract, we should employ such parties to do such portions of the work.

(*d*) Yes.

(*e*) No answer.

Question 38.—Do you recommend horizontal or upright engines?

Answers.—(*a*) We recommend engines of the Corliss type.

(*b*) With more time in which to act we would probably be willing to recommend vertical engines, but they have not yet stood the test of as long experience as have horizontal engines, and, as it is most important that experimental work be avoided, we recommend horizontal Corliss engines, as stated above.

(*c*) Our preference would be for horizonal engines.

(*d*) No answer.

(*e*) We would recommend vertical engines, as before stated.

Question 39.—What is the best form of connection between engines and generators, belt or countershaft?

Answers.—(*a*) In our opinion, the best forms of connection between the engine and dynamo are ropes or belts, doing away with all countershafting.

(*b*) Both should be avoided and direct connection made between the dynamos and engines. In the latest and most improved engineering practice very slow-speed dynamos have been developed, corresponding to the speed of the engine used. If it is necessary to use transmission by either belt or countershaft, belts should be employed without question. Countershafts should be avoided under all circumstances.

(*c*) Our preference would be for direct connection between the engine and generator, not using either belt or countershaft.

(*d*) No answer.

(*e*) We would recommend direct-driven dynamos without belt or countershaft.

Question 40.—Are high or low speeds preferable, and about how many revolutions per minute?

Answers.—(*a*) Low speeds are preferable—300 revolutions per minute.

(*b*) Low speeds—about 100 revolutions per minute.

(*c*) Our preference would be for a medium speed, say 90 to 100 revolutions per minute.

(*d*) No answer.

(*e*) We would consider moderately high-speed engines preferable. In the engines before mentioned the speed would be 100 revolutions per minute, with a piston speed of 600 ft. per minute.

Question 41.—What is the proper size of wheels for motors and for trailers?

Answers.—(*a*) The proper size of wheel for the locomotive is 42 ins., and for the trailers the same as now on the suburban cars—33 ins. diameter.

(*b*) For motor cars, 42-in. wheels; for trail cars, bogie trucks, 36-in. wheels.

(*c*) We should say that the size of the car wheels on motors and trailers should be about 30 ins. diameter.

(*d*) No answer.

(*e*) We would recommend for the proper size of wheels 48 ins. for motor cars and trailers.

Question 42.—What will be the percentage of loss in power between the steam engine and the motor?

Answers.—(*a*) The efficiency of the system will be as follows: Efficiency of engine, 85%; efficiency of dynamos, 94%; efficiency of line, 80%; efficiency of motors, 90 per cent.

(*b*) Between the cylinder of the engine and the pulley of the dynamo there will be a loss from engine friction of about 15 to 20 per cent. There will be a total loss in the dynamo of about 6% in a 500-H.-P. generator, and an average loss between the station and the motors of about 15 per cent. There will be an average loss of about 20% in

the motors. The general efficiency of the system will, therefore, be slightly over 50 per cent.

(*c*) The percentage of loss in power between the steam engine and motor will be about 25%, to which must be added the loss in the motor itself of about 15 per cent. The total loss of energy between the shaft of the engine and the rails will probably approximate 50 per cent.

(*d*) No answer.

(*e*) The approximate loss between the steam engine and motor would be about 15 per cent. This is about equally divided between the dynamos and line.

Question 43.—What is the lowest practicable radius for curves in terminal loops ?

Answers.—(*a*) The curves on the terminal loop should not be less than 100 ft. radius.

(*b*) There will be power in the motors sufficient to carry a three-car train around a 50-ft. circle, and there will be no mechanical difficulties in the way. It is, of course, desirable to have a much larger circle, up to 200 or 300 ft.

(*c*) We think the radius of curves in the terminal loops should not be less than 100 ft., and, of course, it would be better to have the curves of a still greater radius than that.

(*d*) No answer.

(*e*) We think your experience would be a surer guide as to the best practice in the matter of curves, but would suggest, however, that the curves be not less than 150 ft. in radius.

Question 44.—What radius of curvature on the loops, on the supposition that the trains will be empty in going around the loops, and run at a speed of about 5 miles an hour, will make the resistance on the loops equivalent to a speed of about 20 miles an hour on the straight portion of the line ?

Answers.—(*a*) Curves with a radius of about 100 ft.

(*b*) No answer.

(*c*) We have no sufficient data for estimating what curvature on the loops would make the resistance on the loops equivalent to a speed of 20 miles an hour on the straight portion of the line.

(*d*) No answer.

(*e*) The answer to this question depends upon such a number of variables that we are unable to give an accurate answer. Under ordinary conditions of road this varies considerably with the speed the train had when it took the curve, and the rate of acceleration on the curve.

Question 45.—Can air be applied to closing and opening side car doors on passenger trains?

Answers.—(*a*) No answer.

(*b*) Yes, if desired, but, as before stated, we would strongly advise end entrances for this class of travel.

(*c*) We do not feel qualified, without taking further time for investigation, to pass on the question as to the best method of opening and closing the side car doors on passenger trains. We know of no reason, however, why air could not be applied to the opening and closing of these doors.

(*d*) No answer.

(*e*) Air may be readily applied to open and close the side doors of passenger trains, but we would consider this would be objectionable in trains moving at such a high rate of speed, as passengers would hardly become seated before the train left the station, and with an automatic arrangement of this kind there would, no doubt, be considerable injury to the passengers from the doors catching their clothing and limbs.

In addition the author personally visited the works of various electric manufacturing companies in the United States, and also discussed at length the different phases of the problem with electric and mechanical experts. The answers to the preceding questions were furnished after careful and mature deliberation on the part of the electric companies.

In order to illustrate the situation as to track arrangements, Fig. 1 shows the lay-out of the tracks used exclusively by the Illinois Central Railroad for its suburban service, with its different suburban stations. The two heavy black lines on the left of the diagram indicate the two tracks set apart for the exclusive World's Fair business, and the remaining heavy lines show the tracks devoted to the regular suburban service.

In regard to the practicability of handling a large number of people by electric power between the site of the Exposition and Van Buren Street, in the city of Chicago, the author was satisfied it was both possible and practicable to handle as large a number as 20 000 persons per hour between the points mentioned by electric power. He was also satisfied that it was possible and practicable to handle the entire suburban business of the Illinois Central Railroad between Randolph Street and Homewood, South Chicago and Blue Island by electric motive power.

While it would seem in a general way to be self-evident that it would be more economical to generate power at a central station and transmit it to motors by electricity, than to maintain and operate separate and distinct steam plants (locomotives) to propel each individual transportation unit, the practical results so far obtained from a com-

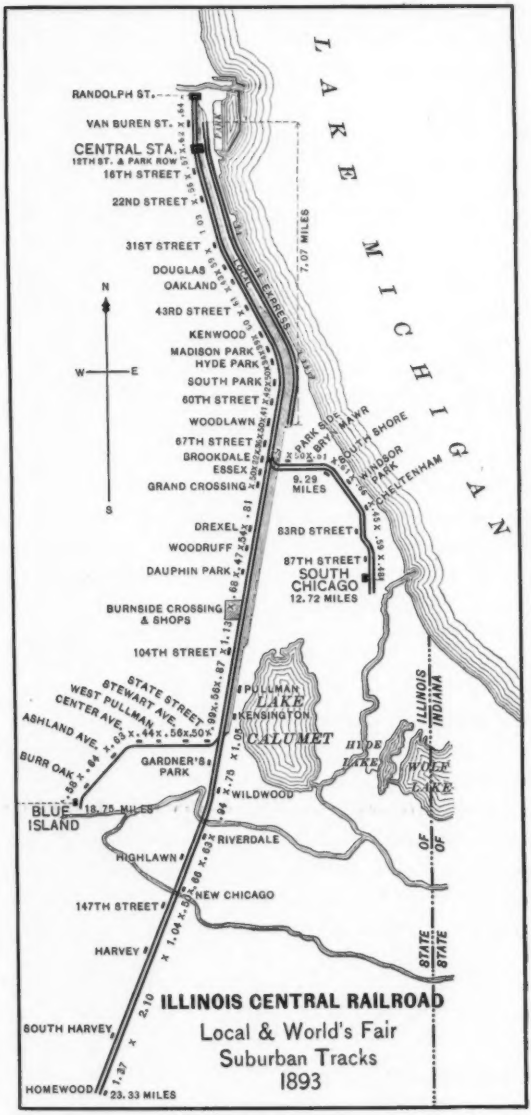
LAKE MICHIGAN
RANDOLPH ST.
VAN BUREN ST.
CENTRAL STA.
12TH ST. & PARK ROW
16TH STREET
22ND STREET
31ST STREET
DOUGLAS
OAKLAND
43RD STREET
KENWOOD
MADISON PARK
HYDE PARK
SOUTH PARK
60TH STREET
WOODLAWN
67TH STREET
BROOKDALE
ESSEX
GRAND CROSSING
9.29 MILES
DREXEL
WOODRUFF
DAUPHIN PARK
BURNSIDE CROSSING & SHOPS
104TH STREET
STATE STREET
STEWART AVE.
WEST PULLMAN
CENTER AVE.
ASHLAND AVE.
BURR OAK
BLUE ISLAND
18.75 MILES
GARDNER'S PARK
PULLMAN
KENSINGTON
LAKE CALUMET
WILDWOOD
RIVERDALE
HIGHLAWN
NEW CHICAGO
147TH STREET
HARVEY
SOUTH HARVEY
HOMEWOOD
23.33 MILES
7.07 MILES
PARK SIDE
BRYN MAWR
SOUTH SHORE
WINDSOR PARK
CHELTENHAM
83RD STREET
87TH STREET
SOUTH CHICAGO
12.72 MILES
HYDE LAKE
WOLF LAKE
ILLINOIS
INDIANA
STATE OF
STATE OF
ILLINOIS CENTRAL RAILROAD
Local & World's Fair
Suburban Tracks
1893
N
S
E
W

FIG. 1.

parison of the cost of operating steam power as applied to steam railroads, and the use of electric power as applied to street car lines, does not bear out the theory. This, however, may be partially accounted for as follows:

In the application of electricity as a motive power, which has only been in use for a few years, and then only to operate street car lines, the engineers giving this matter their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics.

Electricity as a motive power has only been used under the most unfavorable conditions, to operate street car lines with crude motors, poor track complicated with sharp curvature, steep grades and operated by comparatively inexperienced and inefficient men, mule-drivers having frequently been converted into electric motormen.

In considering the present problem, however, the application would be made on first-class standard gauge track, with practically no grade and very slight curvature, except at terminal points; stops would be infrequent, the most improved motors would be used and placed in charge of intelligent and disciplined men, rendering the conditions under which the electric power would be used the most favorable that have ever existed. There was, at the date of this examination, no electric line operated under such favorable conditions with which comparisons could be made, consequently no estimate of the cost of operating an electric system under these conditions could be made more than approximately. In the then existing electric street railway practice operating expenses amounted to 2 to 3½ cents per passenger carried. This was a very favorable showing, however, considering the unfavorable conditions—the use of geared motors, bad roadbed, inefficient management, and the fact that all street railway lines ran large numbers of cars containing but few passengers, some of the larger systems having non-paying branches upon which traffic was very light, which had a tendency to increase the cost per passenger.

There were also several considerations in favor of the adoption of electric power which could not be reduced to dollars and cents, viz.:

First.—The ability to run more transportation units in the suburban service at less expense per unit, than by the use of steam, thereby changing the present steam suburban service from a time

card to a street car basis, doing away with the necessity of passengers waiting for schedule trains and thereby building up and increasing the suburban service.

Second.—The advantage of not being required to stop for coal and water.

Third.—The absence of smoke and dirt.

Fourth.—The possibility of the road being required to use anthracite coal for engines inside the city limits of Chicago, increasing the cost of fuel at least five-fold and largely adding to the cost of steam service, which would of course have a tendency to render the use of electricity economical.

Analyzing the figures obtained from the electric companies, it was estimated that the necessary plant and equipment for operating express trains between the city and the Exposition grounds would cost $1 200 000, divided approximately as follows:

Power plant	$600 000
Wiring and line plant	325 000
Motors in service, extra motors and motor parts	260 000
Repair shop for motors, with necessary machinery and appliances	15 000
	$1 200 000

The annual cost of operation was estimated as follows:

Interest on plant at 5%	$60 000
Operating power plant	85 000
Operation and repairs of motors	101 700
Maintenance of line and wire system	10 000
	$256 700

These estimates were based upon furnishing electric transportation service for the express trains between the city and the Exposition during the Fair period, operating the regular suburban service during the same period by steam, and at the close of the Exposition extending the application of electric power to the entire suburban system. The foregoing estimate would furnish the same maximum capacity per hour as the existing service.

Comparing the estimated annual expense of the electric application with the actual cost of the steam service for the year ending June 30th, 1891, shows the former to be $144 200 in excess of steam for motive power alone. While it is true that trains could be run at more frequent intervals at the same cost, there would, of course, be some additional expense for an increased number of trainmen, etc.; still the electric application would give an increased capacity during a part of the day, which might stimulate and add to the suburban business. In order to justify the extra outlay, however, there would have to be an increase in the suburban business over the year ending June 30th, 1891, of approximately 25 per cent. This would be necessary to offset the extra cost of making the electrical application.

In considering the question of steam versus electricity for the business due to the Exposition, it was found that it would be much more economical to use steam power for this service, and that the equipment necessary for it could afterwards be used for other purposes. It was deemed that it would be advisable, particularly during the busy hours of the morning and evening, to run large units of transportation, as the time consumed in loading and unloading a train would be the same regardless of the length of the train, due to the system which had been decided upon of loading and unloading trains to and from high platforms directly into and out of the sides of the cars, and which afterwards proved so successful; and that it would be safer and more economical to carry a great number of people on heavier trains and run them greater distances apart, rather than have a large number of smaller trains running at short intervals of time. No difficulty was apprehended in running trains of ten or twelve cars each, with a capacity of 1 000 passengers per train, at intervals of three minutes, which would give a capacity of 20 000 passengers per hour. The history of the Exposition more than bore out this theory, as on one night during the hour of heaviest travel, 45 trains were dispatched from the Terminal Station in the Exposition ground, carrying from 1 000 to 1 200 persons each. This was the maximum number of passengers carried in the shortest period of time, and more than exceeded previous expectations.

A factor also in this connection was the fact that it would require from 45 minutes to one hour to make the trip from the Exposition to the heart of the city by the existing cable lines, and at least 30 minutes

by the elevated road; that if electric power was used on the Illinois Central, the tracks would be occupied by such a large number of small units of transportation that it would not be feasible to run them at the speed which would be possible in the handling of large units of transportation by steam at less frequent intervals; and that it would be possible to handle trains between the heart of the city and the Exposition grounds by steam in less than 20 minutes, which would have a tendency to increase the patronage of the Illinois Central line. Experience afterwards proved the correctness of this view, as the average time of the express trains between Van Buren Street and the Midway Plaisance was approximately 12 minutes.

It was therefore decided that while the application of electricity as a motive power might be practicable, it would not be the economical thing to do, and that it was specially undesirable in providing for the large business contemplated during the holding of the Exposition to introduce any elements of uncertainty. The results which could be obtained by the use of steam power were known and definite, both as to economy, efficiency and speed, and it was not considered advisable or economical to adopt electric power for this service.

Deciding the second proposition in the negative rendered it unnecessary to consider at any length the question of appliances except incidentally in determining the question of the economy of electrical application.

It was considered by the author at that time, that, as the use of electric power was rapidly advancing, results would be obtained in the near future which would render its adoption practicable and economical, particularly for terminal and suburban lines.

At the time of this investigation, five years ago, while success had been obtained in the adaptation of electricity to street railway systems and small units of transportation over short distances, its application to the larger requirements of terminal and suburban service, which had heretofore been performed by steam power, was yet experimental. The requirements of the Illinois Central service were approximately ten times in excess of the then existing practice, and the adoption of electric power for Illinois Central business, either for World's Fair or the regular suburban traffic, would have been largely experimental and the estimates of the cost of maintenance and operation only approximate.

In discussing verbally the question of appliances, much stress was laid by the representatives of the various electric companies upon the speedy adoption of what is known as the gearless motor; and while they expressed every confidence in the gearless motors which they were manufacturing and had in process of perfecting, the written propositions of some of the companies contemplated the use of single-reduction motors.

The statements of the various electric companies differed largely as to the expense of the application of electric power. For the same capacity their figures varied from $375 000 to $1 200 000. Their opinions of the amount of horse-power needed ranged from 5 000 to 18 000 H.-P. The differences in the estimated cost of operating the power plant per day ran from $232 to $616. In their estimates of the amount of fuel needed per horse-power per hour, the variation is from 2 lbs. to 3½ lbs. of coal. The figures on motors ranged from $7 500 to $10 500; and the cost of operation and repairs of motors per day from $286 to $430. There was a variation in the estimates of the cost of trolley lines and feed wires of from $40 000 to $172 000, and variation in the estimate of repairs to same and other line expenses from nothing to $23 50 per day.

During the five years since this problem was considered, great advances have, of course, been made in the application of electric power, and the cost of appliances has been largely reduced. More certain and reliable data is also doubtless available as to its economy and the cost of maintaining and operating electric power. A number of steam railroad companies are seriously considering the question of replacing their locomotive engines by electric motors for suburban business, and it seems that the general question opens up a wide field for discussion, the results of which should bring into the *Transactions* of the Society a large amount of valuable matter in the line of electric engineering.

Comparing the use of steam and electricity as motive powers, as a general principle it may be stated that electricity is more desirable and economical for handling a large number of small transportation units at frequent intervals over short distances; whereas, steam power is more desirable and economical for handling large units of transportation at high speeds, at infrequent intervals and over long distances. In treating of special applications, it may be further said that the increase in the use of electricity will grow along these general lines.

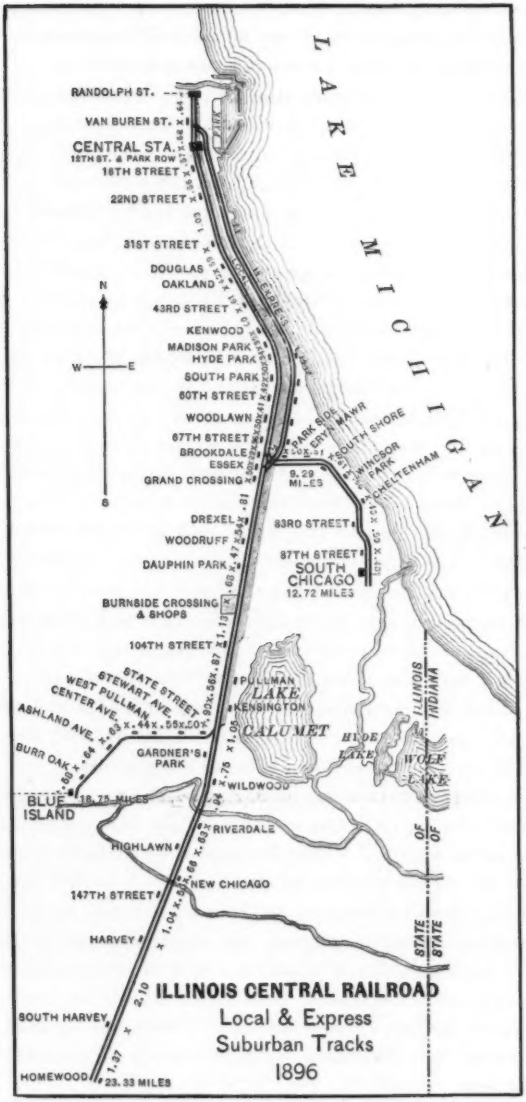
LAKE MICHIGAN
RANDOLPH ST.
VAN BUREN ST.
CENTRAL STA.
18TH ST. & PARK ROW
16TH STREET
22ND STREET
31ST STREET
DOUGLAS
OAKLAND
43RD STREET
KENWOOD
MADISON PARK
HYDE PARK
SOUTH PARK
60TH STREET
WOODLAWN
67TH STREET
BROOKDALE
ESSEX
GRAND CROSSING
9.29 MILES
DREXEL
WOODRUFF
DAUPHIN PARK
BURNSIDE CROSSING & SHOPS
104TH STREET
STATE STREET
STEWART AVE.
WEST PULLMAN
CENTER AVE.
ASHLAND AVE.
BURR OAK
BLUE ISLAND
18.75 MILES
HIGHLAWN
147TH STREET
HARVEY
SOUTH HARVEY
HOMEWOOD
23.33 MILES
PARK RIDGE
GRYMAWR
SOUTH SHORE
WINDSOR PARK
CHELTENHAM
83RD STREET
87TH STREET
SOUTH CHICAGO
12.72 MILES
PULLMAN
LAKE
KENSINGTON
CALUMET
HYDE LAKE
WOLF LAKE
ILLINOIS
INDIANA
GARDNER'S PARK
WILDWOOD
RIVERDALE
NEW CHICAGO
STATE OF ILLINOIS
STATE OF INDIANA
N
S
E
W
ILLINOIS CENTRAL RAILROAD
Local & Express
Suburban Tracks
1896

FIG. 2.

Where the substitution of electricity for steam is considered, the question of the disposition of the abandoned steam plants and the amount of money invested therein becomes a factor.

This matter of applying electric power to its suburban service is again under consideration by the Illinois Central Railroad. Fig. 2 is a diagram showing the tracks now devoted exclusively to this service in the city of Chicago. The change from the conditions that existed in 1891 consists in the use of the two west tracks between Randolph Street and Grand Crossing for the local suburban business, trains between these points being so operated as to give a continuous service with trains 20 minutes apart during the hours of light traffic, and from 5 to 10 minutes apart during the busy hours of morning and evening. Ordinarily, these local trains only run as far south as Sixty-third Street, the suburban business from the South Chicago branch, the Blue Island branch, and from the main line at Homewood, Harvey, Kensington, etc., being diverted at Sixty-seventh Street to two tracks along the east side of the right of way, and after making local stops at Sixty-third, Sixtieth, Fifty-seventh and Fifty-third Streets, running from there without stop to Van Buren and Randolph Streets in the city. This forms what is known as the express suburban service. Trains run 20 minutes apart during the day, and 10 minutes apart in the morning and evening, when the traffic is heaviest. The location of these express suburban tracks is such that they are not cut by facing-point switches north of Sixty-seventh Street except at two places; at one of these a Wharton safety switch is used and the other is controlled and protected by the interlocking plant at Forty-third Street. No street crossings exist between these points.

The problem now under consideration is the practicability, desirability and economy of adopting electricity as a motive power for this entire suburban system. Under this general head come minor problems as to the partial adoption of electric power for either the regular or express suburban service or parts thereof, as to the proper location and arrangement of a power house and plant; what system shall be used for the transmission of power; the size of transportation units; whether independent motors of large power should be used to haul long trains of trailers, or whether small transportation units run at more frequent intervals should be adopted, using the motors for carrying passengers.

Following is the present amount of equipment assigned to this service: Twenty-one engines, having 16 x 22-in. cylinders, 49½-in. drivers, four-wheel; weight, 117 000 lbs. Two engines, having 18 x 22-in. cylinders, 49½-in. drivers, six-wheel; weight, 160 000 lbs. Ten engines,

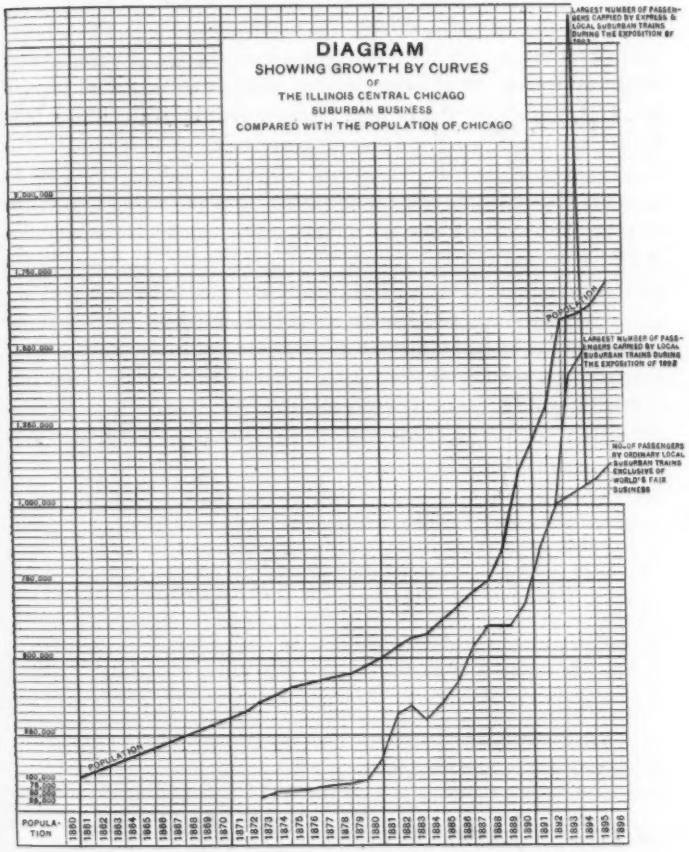
DIAGRAM
SHOWING GROWTH BY CURVES
OF
THE ILLINOIS CENTRAL CHICAGO
SUBURBAN BUSINESS
COMPARED WITH THE POPULATION OF CHICAGO
LARGEST NUMBER OF PASSENGERS CARRIED BY EXPRESS & LOCAL SUBURBAN TRAINS DURING THE EXPOSITION OF 1893
POPULATION
LARGEST NUMBER OF PASSENGERS CARRIED BY LOCAL SUBURBAN TRAINS DURING THE EXPOSITION OF 1892
NO. OF PASSENGERS BY ORDINARY LOCAL SUBURBAN TRAINS EXCLUSIVE OF WORLD'S FAIR BUSINESS
POPULATION
1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873 1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896

FIG. 3.

having 17 x 24-in. cylinders, 49½-in. drivers, four-wheel; weight, 166 000 lbs. In all, 33 engines valued at $8 500 each; total value, $280 000. The suburban coaches in use number 162; they are 45 ft. long and average a seating capacity of 54 persons; value, complete,

with steam heat and Pintsch gas, $3 500 each; total value, $567 000. The grand total value of suburban equipment amounts to $847 500.

Fig. 3 is a diagram which shows the increase in the population of the city of Chicago from 1860 to date; also in finer black lines the ratio of increase in Illinois Central suburban business by years. The figures on the left-hand margin show the population, without any reference to the number of passengers carried by the Illinois Central suburban trains. The actual number of passengers carried is not indicated, but simply the ratio of increase year by year. From 1892 to 1894, the lower line shows the suburban business as it would have been unaffected by the Exposition. The lines extending upwards show the proportionate increase in the business due to the Exposition on both the local and express services. The rate of increase in the city's population and the Illinois Central suburban business show a diminished ratio in 1893 and 1894, which was due, so far as the population is concerned, to financial conditions in those years, and as regards the suburban business to the same general influences, together with the competition of the "Alley" elevated line and the growth of local electric lines in outlying districts. It will be noticed that during last year the rate of increase in population and suburban business has again taken an upward turn.

DISCUSSION.

Mr. Clarke. T. C. Clarke, Past-President Am. Soc. C. E.—The wide differences in the cost of the application of electric power, in the opinion of experts, varying from $375 000 to $1 200 000, and of its operation, varying from $232 to $616 per day, shows how little was definitely known about the matter five years ago. The decision of the Illinois Central Railway Company to make no change from steam locomotives would have been justified for that reason alone, but the author has pointed out a much better reason, that the greater part of the Exposition business consisted of carrying large numbers of people from one terminal to another. This indicated long trains of cars at greater distances apart, say twelve cars carrying 1 000 passengers. There is no question that the steam locomotive is the most economical means of doing this class of business. When he comes to consider the question of the application of electricity to suburban traffic, he states the whole case very clearly and correctly. "Electricity is more desirable and economical for handling a large number of small transportation units at frequent intervals over short distances, while steam power" (meaning steam locomotive power) "is more desirable and economical for handling large units of transportation at high speeds, infrequent intervals, and over long distances." He should have added that the electric system is better adapted to frequent stops, and the steam locomotive to stops far apart.

The author, under the head of "minor problems," speaks of "the size of transportation units and whether independent motors of large power shall be used to haul long trains of trailers, or whether small transportation units, run at more frequent intervals, shall be adopted," with motors on the cars. In designing the rolling stock and structure of elevated electric railways in cities, this is the main point, and not one of minor consideration. Neglect to study this and to come to the correct conclusion has led to the financial failure of one of the largest electric elevated railways that has been constructed, and will lead to the financial failure of all others that follow the same lines.

Carrying passengers in a city does not differ from any other business. The first requisite is to get abundant traffic; the second, to handle it with economy. The Manhattan Railway is an instance of the first; the Brooklyn Elevated of the second.

Elevated lines run in competition with surface lines, and charge the same fare. The surface lines can beat them in all points but one. They afford more frequent stops; there is no climbing of stairs; cost of construction and, consequently, interest is less, and the system of transfers to branch lines is a great accommodation to the public. The elevated trains, not being impeded by surface traffic, can make better

Mr. Clarke.

time; but for that, no person would ride in them, except to escape crowding.

Common sense would indicate that the managers of elevated lines should try to approach, so far as possible, the conditions which have made surface lines a success.

Frequent stops can only be attained, without losing too much time, by having a great power of acceleration. Any amount of power can be sent from the central reservoir, but if the wheels of the cars slip, a limit is reached. Therefore, instead of having only one-third of the weight of the train available for adhesion, as is the case where an electric locomotive draws a train of trailers, utilize the whole weight of the train and passengers by putting motors on every car, connected electrically and mechanically, and worked by a motorman at one end of the train. Another advantage resulting from this is that gradients can be steepened and the height of the stations and their stairways reduced.

If, in addition to this, short trains of light cars are used, the weight and cost of the structure can be greatly reduced, and the interest charges also. Small trains mean frequent trains to enable the traffic to be carried, and everybody knows there is no means of attracting traffic so powerful as that of frequent trains, as there is then no waiting at stations, which everybody hates.

The summing up of the whole matter is, that to make a city elevated railway a success, the surface electric system must be copied, and placed above obstructions from other traffic, and not the steam locomotive system of long trains at greater intervals.

Some persons say that this last method is a much more economical one of carrying traffic. Even if this were true, it would not be a strong argument, if there were but little traffic to carry. The statement does not seem to be borne out entirely by the facts. The cost of carrying passengers on the Brooklyn elevated steam railway for 1896 was 10.6 cents per car-mile run, and the number of passengers carried per car-mile run was 3.66. The Brooklyn surface trolley lines carried during same year 4.76 passengers per car-mile run, and at a cost per car-mile of 12.10 cents. The cost of carrying passengers on the Manhattan elevated lines in 1896 was 12.2 per car-mile run, and the number was 6 per car-mile run. The cost of carrying passengers on the Third Avenue line during same year was 11.94 cents per car-mile run, and the number was 5 per car-mile run.

All surface trolley lines would prefer, if conditions allowed it, to be able to run one motor car with one or two trailers. If they were placed on elevated structures of light construction, they could do this, and if motors were attached to all the cars, they could run more or less of them to suit the variations of traffic, and in case of a breakdown of the motors on one car there would always be a motor car at hand to take it away.

The process of evolution which develops everything along the fittest lines will make the city elevated railway of the future one of light structure, carrying light and very frequent trains, with motors on the cars themselves—a development of street trolley lines, and not of steam locomotive railroads. Mr. Clarke.

HENRY G. PROUT, M. Am. Soc. C. E.—It is improbable in the light of present knowledge of the subject that the traffic now handled by steam traction, if carried in the same manner and at the same intervals, could be handled cheaper by electricity. It would not be surprising if this statement were found to hold true of the Manhattan Elevated Railroad in New York, which is admirably adapted for economical electric working because the traffic is such that the central power stations could be operated under a condition of fairly uniform loading. Nevertheless the traffic on this road is handled under conditions giving great economy in steam traction; that is to say, the units are large, and could not be reduced even were electricity substituted for steam. It would be unsafe to run the trains at more frequent intervals then they are run now. Consequently to handle the same traffic, it is necessary to operate trains as heavy as those now in service, and it is possible that a thorough analysis of the problem would show that they could be handled more cheaply by steam than electricity. In 1895 the then general manager of the company stated that no one had been able to convince him of an economy in handling the traffic of the Manhattan Elevated Railroad by electricity which would pay the interest on the cost of the change. The present general manager, however, has the contrary opinion. Mr. Prout.

If the traffic can be massed in such a way as to be handled in large units it is probable that steam will handle it more cheaply than electricity for a long time to come, so far as can be foreseen now. It may be assumed, for instance, that the traffic can be hauled by a locomotive capable of developing 1 000 H.-P., and costing, say, for simplicity, $10 000. A central station of 1 000 H.-P., with the means of transmitting the power to the motor, will cost $80 000, taking about the mean of the author's figures, which range from $65 to $100 per horse-power. The interest on the difference in cost of a 1 000 H.-P. central station system and a locomotive of equal capacity would be more than the saving in the cost of coal effected by the use of electricity; moreover, it is questionable if there would be any appreciable saving in coal consumption. To generate and deliver a horse-power at the driving wheel of an electric car will probably require as much coal to be burned in the central station as in the locomotive, but it is true that cheaper coal may often be used in a central station than on a locomotive.

It is thus evident that the problem is more commercial than engineering. In order to secure traffic of the class discussed by the

Mr. Prout. author, it must be handled in small and frequently operated units. Owing to the competition of trolley roads, the question of the possible maximum economy is over-shadowed by the more important problem of securing and holding the traffic, even by more expensive methods of handling than those of the present time. Under the present systems of headway and speed, the business now done can be carried on more cheaply by steam than electricity, but the problem confronting the railroads is that the present business cannot be retained by such a service, which points to the application of electricity for certain limited uses.

Mr. Emery. CHARLES E. EMERY, M. Am. Soc. C. E.—The detailed information in the paper is more valuable from a historical standpoint than otherwise, because the development of electric traction in the last five years has been great. While the paper contains what may be termed predictions of possibilities by those who had investigated the subject thoroughly and have since proved they were right, it also contains considerable data from those who merely had ideas on the subject and had not proved them, which accounts for the variations in the estimates submitted.

The general principles underlying the introduction of electric traction are now pretty well understood. Where the traffic is handled by frequent, short trains, electricity has the advantage, while with heavy, long trains the advantage lies with the steam locomotive. So far as economy alone is concerned, it is probable that the steam locomotive nearly holds its own in a comparison with trolley practice, but there are other aspects of the problem to be considered.

In an approximate investigation of the cost of applying electricity to the Pennsylvania Railroad, 1 800 miles long, the speaker assumed the present movement of trains as a basis and estimated the cost of electric apparatus at the lowest figure yet discussed, or at about the same cost per pound as other classes of machinery. The cost of operation was also taken as low as seemed possible in practice. On this basis it was found that to run all trains on the road electrically instead of by steam would necessitate increasing the present gross receipts about one-tenth to pay the same dividends as at present. It follows that to make the substitution of electricity for steam profitable the traffic must be increased, as has been the history in changing horse to trolley lines.

An analysis of the cost of operating steam and electric roads is interesting. In the case of electricity, the loss from the power station to the rails is about 50% in round numbers. With an improved steam plant in the station the saving in fuel per horse-power delivered at the track would be about one-third of that required by the locomotive.

The probable difference in price of fuel would increase the saving to one-half. The saving in weight, due to the absence of the tender,

Mr. Emery.

applied to the relative amount of coal used for different classes of engines, would increase the average saving in fuel to about 53 per cent. When it is considered, however, that the cost of fuel on railroads is only about one-tenth the total operating expenses, the saving would only be 5.3% of the operating expenses, which would be increased to about 6% when the saving in water is considered. The saving in fuel does not therefore affect the problem to a very important extent. In the case of a standard steam road there are many reasons why it is desirable to use an independent electric locomotive. In such a case the same number of trainmen would be required as for a steam locomotive and no reduction in their wages can be predicted, The use of electricity would make a slight reduction in the force of cleaners in the round-houses, but add the wages and other operating expenses of the large stations where the current is generated.

The use of electricity will also entail additional interest charges due to the cost of the generating station and its equipment and the overhead or third rail system of transmitting power from the station to the trains; and in equipping an old railroad already supplied with locomotives, the capital account will also be increased by the cost of the electric locomotives.

It is evident that the electric operation of a standard steam railroad makes it necessary in order to earn the same amount for dividends as at present, to increase the gross earnings sufficiently to meet the additional fixed and labor charges, less the comparatively small saving in fuel.

In the case of suburban steam traffic the reasoning is the same, except that at moderate speeds the motors can be put under the baggage car and driven by a single man, with the baggageman acting as a reserve in case of sickness or accident to the driver, so there would be a slight saving in the cost of labor. It is a curious fact, however, that the cost of operating the better class of railroads is about the same, whether they use trolleys, cables or steam locomotives, and is independent of the size of cars. It is merely an accident, due to the fact that the force required to pull a train on a standard steam road is less than that necessary on the dirt-covered trolley roads, the difference being due to the condition of the track. This cost of operation runs from 5 to 15 cents per car-mile, although there are few examples at either limit. The cost usually ranges from 10 to 12 cents per car-mile. The chief reason for the high cost in the case of trolley roads is due to the item of labor, the most noticeable example being afforded by the West End Railway in Boston. The use of the trolley in this case did not enable any improvement to be made in the average speed of the cars on account of congested streets, more capital had been invested, and more men employed to handle the increased traffic, so there was no reduction in the cost of operation per car-mile. Un-

Mr. Emery. doubtedly when the subway in Boston is finished, the cars will average a higher speed and more car-miles will be obtained than at present for the same or a less total expenditure.

Why has the trolley been successful? Partly because the power has been furnished more cheaply and conveniently than by horses, but chiefly because it enables the public to be served better. The cars stop where desired, make fair speeds, and avoid the climbing or descending of stairs incident to travel on an elevated railway. It is perfection for city traction and approaches it for suburban traffic, but for reasons given it is safe to predict that further electric developments will, for the present, be on suburban lines and not on steam operated roads.

Mr. Bates. C. J. BATES, M. Am. Soc. C. E.—The fundamental point in this discussion is whether or not any system of electric traction has been devised which will meet the exigencies of standard railroad operation. When this matter is settled, it will be time to discuss economies and details. No such system has yet been devised, and the trolley system for anything like trunk-line traffic may be said to be totally worthless. If any engineer will take the trouble to sketch out a yard where there is a complicated system of tracks, and endeavor to locate his pole and overhead wires where they cannot be reached by the rolling stock moving about the yard, he will see that the trolley system cannot be used.

In the important matter of taking up current from the conductors to operate the motors, but little improvement has been made since the author made the investigation on which the paper is based. It is reported that the third rail on the Nantasket road is to be divided into separate insulated sections. This, however, adds another difficulty, sparking, for the electric locomotive to overcome in moving from one section to another. This might be obviated by putting a motor on each car and arranging a method by which every car would take current from the third rail.

Mr. Hutchinson CARY T. HUTCHINSON, Assoc. M. Am. Soc. C. E.—The most sanguine electrical engineers have never seen quite such a rosy prospect for electric traction as Mr. Emery has presented in his statement that 10% increase in the gross receipts of the Pennsylvania Railroad would make electrical operation perfectly feasible. All electrical engineers have taken the position that there can be no substitution of electricity for steam on trunk railroads. The only condition under which electricity can be used successfully is where the load is strongly concentrated, when there are many units running under a short headway.

Enough stress has not been laid in the paper on the fact that the answers to the author's questions were made six years ago. At that time the parties asking the questions were groping in the dark, as everybody now knows. It has also not been clearly brought out that

all the questions were not clear-cut, and the conditions were not fully defined. This accounts for much of the confusion between the replies. Another cause was the difference in opinion as to the meaning of terms. In answering Question 40, for example, a speed of 100 revolutions per minute is variously stated as high, medium and low. Apart from this matter, however, it may be said that two or three of the companies could have installed the desired plant successfully. In the Baltimore and Ohio tunnel work, the conditions were more onerous and differed more from trolley practice than anything attempted at Chicago, but the undertaking was carried out with entire success by one of the companies tendering for the Illinois Central contract. Mr. Hutchinson

The subject of elevated railroad operation has been presented in a manner not quite fair to electricity, in the statement that there could be no saving in operating expenses, because the trains would probably have to be of the same size in order to accommodate the traffic. The conditions could be met by changing the size of the units as the traffic changes, employing independent driving for each motor, and increasing the carrying capacity as the traffic increases. This plan has been proposed, and there seems to be no reason why it should not be carried out, except the difficulty of controlling the motors of a number of individual cars. The locomotive does not fit the work at all, and separately driven motor cars will be used in all probability. Another objection which has been raised to the use of electricity in yards is the complication of poles and overhead wiring, but no one would attempt to use the overhead trolley under such conditions. Some surface method, such as a divided third rail, would be adopted.

W. H. KNIGHT, M. Am. Soc. C. E.—The electric motor is handicapped to a certain extent as compared with reciprocating motors by the pulsations of its power. Unless an elaborate rheostatic means of controlling the current is used, the power is bound to be applied in more or less uneven steps, quite as uneven as the variations in horizontal effect due to the angularity of the connecting rods of a steam locomotive. Mr. Knight.

At the time the company with which the speaker was then connected submitted its estimates to the author for the work mentioned in the paper, it was also discussing two more untried problems in electric traction, the Intramural Railway of the Columbian Exposition and the 100-ton locomotive for the Baltimore and Ohio tunnel. Both these problems it solved successfully, although there were a few disappointments, and some of the things prophesied would not come about. At that time estimates were sometimes made by people who had absolutely no experience with the subject, which naturally threw suspicion on every one.

In regard to the elevated railroad problem, which is more directly interesting to electricians than steam traffic generally, because of the

Mr. Knight. possibility of avoiding trolley wires, the direction in which progress lies is apparently in the line of longer trains moving more rapidly. The whole object of the elevated railroad is speed, and speed cannot be had with short headways. If it were merely a matter of carrying the greatest number of people, a comparatively slow speed and short headway would solve it. On the New York and Brooklyn Bridge a speed of 6 miles an hour will carry the greatest number of people. A speed of 15 or 16 miles could be attained, but the motive power expense would have to be doubled, which is inadmissible. Electricity is now able to handle trains of five to ten cars at a speed of 13 miles per hour without increasing the weight of the elevated structure over what it is at present. The steam locomotive can make only 11 to 12 miles an hour, because it would otherwise have to carry too great a load on the drivers for the safety of the structure, and because it cannot be moved quickly at the terminals. The electric motor, being an integral part of the train, does away with the need of shifting engines. If the Manhattan Elevated Railroad Company ever solves the problem of earning larger dividends, it will probably be by running longer trains at greater speeds, and not by dividing the trains into smaller units run on shorter headways. To do this it would, of course, be necessary to improve the facilities for loading and unloading the cars. It would make little difference, so far as speed is concerned, whether the cars were all equipped with motors, or all the electric apparatus concentrated on one car. The company with which the speaker was formerly connected advocated concentrating the apparatus, for the reason that one car gives sufficient weight, distributed over eight wheels, to afford all the traction needed.

CORRESPONDENCE.

Mr. Barrington.

EDWARD BARRINGTON, Esq.—There is hardly any doubt as to the practicability of substituting electricity for steam as a motive power for suburban traffic. The economical aspect of the question can be figured closely by those familiar with the subject, as they have had ten years' experience on the street railways, together with that of the several steam roads now using electricity, on which to base their calculations.

Motor cars having a capacity of 100 H.-P. each, but capable of developing up to 200 H.-P. for short periods, should be able to handle the present service of the Illinois Central Railway, and the power should be divided between two motors.

The answers to the author's queries seem to have developed quite a diversity of opinion and information. It would probably take 6 000 H.-P. to cover satisfactorily the suburban traffic of the Illinois Central, including the several branches, which would be divided into four units of 1 500 H.-P. each, and eight dynamos of 750 H.-P. each, with Babcock & Wilcox water-tube boilers, mechanical stokers, condensers, heaters, separators, and all accessory apparatus. The approximate cost of power station, plant, line, block-signal system, thirty-three combination motor cars, etc., should not exceed $750 000. This does not cover cost of site for power plant. There is no real necessity for any loss being incurred through inactivity of the present suburban equipment, as the locomotives can be used elsewhere, and the coaches will remain in active service. At $1 per ton for coal, the cost of operation, with careful management, should not exceed $25 per horse-power per annum. An electrical engineer, thoroughly conversant with mechanical engineering, would be quite essential.

Although the writer's estimates are based on the overhead system of transmission, he strongly advocates the third-rail system with low voltage. With ordinary precautions, no danger need be counted upon. The difference in cost between the third-rail system and the overhead system would not be material. With the latter the poles should be placed between the tracks, from 90 to 100 ft. apart, and the wires supported by the bracket suspension method. Trolley wires should be No. 00, B. & S. gauge, and feed wires No. 0000. With first-class construction, the cost of repairs would be merely nominal. Fifteen per cent. of extra equipment should provide for repairs and contingencies. The repair shop should be thoroughly equipped with the best tools, etc., and be under the supervision of the engineer in charge. The motor cars should be built on the vestibule plan, thus protecting the motorman from the inclemencies of the weather.

Many railway managers, and more especially those connected with eastern roads, have pretty much made up their minds that it is not merely a theory that confronts them, and that if they wish to hold

Mr. Barrington. their patronage and pay dividends they must fight electricity with electricity. Although electricity will undoubtedly supersede steam in the not-distant future, there does not appear to be the slightest reason for uneasiness on the part of any existing interest, as such changes will take place in conformity with well-defined laws of progress, which must infallibly operate to compensate adequately for all apparent losses incurred during the period of transformation, and will have their analogy, so far as economic consequences to existing interests are concerned, in the change from the horse-car or stage coach to the electric motor car or steam locomotive.

It has been carefully estimated that the adoption of electricity in place of steam on trunk lines would effect a saving of from 10 to 15% of their operating expenses annually. Included in this are the repairs, fuel, water and other supplies for locomotives, and wages of firemen. All items in which there may be a reasonable doubt are eliminated, and the steam power given the benefit of the doubt. It is problematical whether any saving could be effected in conducting transportation, wages of trainmen, repairs of roadbed, renewal of ties, repairs of bridges, repairs of shop machinery or wages of engineers.

In estimating the initial cost of installing a railroad with an electrical equipment, several methods are employed to determine the amount of power needed, as follows:

Take the number of miles run per year by all trains and reduce to an hourly traffic and multiply by the power required per train.

Take the yearly movement of freight and passengers, and reduce it to an hourly basis, with proper allowances.

Take the number of locomotives and multiply by the average power developed by each, making proper allowances for engines not in use.

Take the coal consumption and assume a certain consumption per horse-power-hour.

Of course each of these reductions should arrive at the same conclusions, nearly.

The last estimate is probably the most accurate, and 25% is added to allow for increased traffic at certain seasons of the year, and 25% again to cover the heaviest demands during the day at such times. This gives the grand total required. It is necessary, therefore, to figure on about 2.4 times the amount of power required on an average.

The power stations should have a capacity of about 6 500 H.-P., and this should be sufficient, generally speaking, for a 45-mile section of road. The equipping of each station will cost about $625 000. Motors will cost about $6 000 each. The net annual saving in operating expenses is figured at 11% on the total cost of installation.

There is not a line of railway in the United States more favorably situated to introduce electric traction than the Illinois Central, and

the power station could be advantageously located at either Grand Crossing or Burnside Crossing, whichever presents the best facilities for furnishing good water for condensing purposes. Burnside Crossing is peculiarly well adapted for a power plant for many reasons. Mr. Barrington.

Most electric railways pay too much for their power. Some develop it cheaply and waste it on the line; others develop it at high cost, while they distribute it and utilize it economically, while others again may be losing at only the motor end of the line. When the steam locomotive is discarded, the most economical and convenient method will be to put the motor under a baggage or combination car, weight being unnecessary, because of the fact that the even pull at a tangent to the circumference of the motor armature produces an apparently greater possible traction effort per ton of weight than is the case with a reciprocating motor, and in addition reduces the tendency of the wheels to slip at starting. This feature of the electric motor is the one above all others which establishes the fact that it has come to stay, no matter what development may be made in air, gas or other motors which have to convert a reciprocating into a rotating motion; and the fact that an electric motor supplied directly from a central station has a practically unlimited supply to draw from puts it far ahead of any motor which carries its supply upon its back, whether it be in air-tanks, storage batteries, oil reservoirs or coal and water bunkers. Where the motor cars are equipped with double motors and two controllers, there is no one thing can happen to prevent the motorman from getting his car or train to its terminus. The speed may be decreased, but the train can be moved. Of course, this presupposes a feeder system practically impossible to interrupt, which will come with the advent of electricity on steam roads.

Experience with power plants shows that the transmission of electric energy a distance of 50 miles with a pressure of 20 000 volts is practicable; beyond this limit the transmission would be more or less experimental. Commercial transmissions are in successful operation for distances of 35 miles, and as high as 15 000 volts. The best plan for the long-distance transmission of energy for general purposes is the three-phase alternating system. Where batteries are used, it is best to place them at the end of feeder wires to obtain the advantage of a constant load on the wire. When the economical area of direct distribution is passed, boosters should be employed directly or in connection with batteries, to a distance of 10 or 12 miles from the station, and beyond this, rotary transformers, with or without batteries, should be used. Where the power is generated in or near the area of distribution, it is best to use one station situated at the most economical point for producing power. Local conditions, of course, largely influence such matters.

Mr. Barrington. Relative to electric distribution, the booster system would probably be the most advantageous on the author's lines, owing to the variable nature of the traffic, both during the day and for different seasons. If any transforming device is employed to feed a distant section of the lines, it must be remembered that the capacity of the device must be great enough to care for the maximum demand on this section. Should it be necessary to feed some line where the load has considerable momentary fluctuation, but where the traffic is moderately constant during the year, the booster could be used with a storage battery at the end of its feeder, the battery supplying the line. The advantages of this combination are greater than with the simple booster, and in many cases they will compensate for the interest and depreciation on the battery and the loss in it. If the arrangement is properly made, the load on the booster and line wire will be practically constant, thus decreasing the capacity of the booster to that required for the average load, while less copper will be required for a given loss. The battery should be located near the points of consumption and not in the station. By this system, a booster with storage batteries, it is possible, assuming the same loss, to transmit power to a distance of 10 miles with approximately the same amount of copper that would be required for a 5-mile transmission on the direct system. It increases the economical radius of distribution twice, and the area of distribution four times. There is little possibility of the complete shutdown of such a station with a proper reserve, a careful system of duplex steam piping, and with fire-proof construction of the station. Storage batteries would look out for any momentary interruptions on the feeders.

The selection of the site of the power house is a very important factor in the economical operation of the road. Striking advances are noted in the plans under which they are now constructed compared with those of some years ago. The distribution of room is more sightly and economical. The false economy of building only for present needs has been observed.

Determine carefully the required capacity of the engines, generators and boilers, and be governed accordingly in the erection of the plant. Closely estimate the amount of generating capacity required, taking always into account the grades and curves, nature of holiday service, frequency of stops and other governing considerations. Having settled upon the capacity of the generators, proceed to determine the capacity of the connected engine, but bear in mind that an engine has not the capacity for excessive overload that a generator has, and that an engine is not called upon to perform more than 20% or 25% above its rating, even for a short time. With regard to the boiler power, it is obvious that it has only to deal with the average of the total load.

As prime movers gas and oil motors are now receiving much consideration, and there is doubtless a great future before them, the working cost per kilowatt being much reduced. Mr. Barrington.

Direct or indirect driving seems to be an unsettled question. For steam-driven plants, direct driving is an undoubted advantage, although it must be borne in mind that a fly-wheel suitable for electric-light dynamos will not be large enough for traction purposes, since in the latter the load fluctuates very rapidly between zero and the maximum. Heavy fly-wheels are very essential. The direct-coupled plant will cost slightly more than the direct-belted with independent engines, but much less than any plant based on large engines, with the attendant mass of counter shafting, clutch pulleys, belts, belt-tighteners, etc. Add to this, the real estate and building item, and the chances are in favor of reducing the original investment one-half in an ordinary plant. The relation of this fact to dividends is apparent.

Frequently the cost of operating power stations is figured from the basis of car-miles. This is liable to be deceptive, as insufficient copper, poor bonding and defective car equipments will make a bad showing for any station. The correct method is to note the output at the bus-bar, and figure upon the basis of electrical horse-power.

The study of the details of such a plant as would be required to operate the Illinois Central suburban service, including express trains and the branch lines to Blue Island, Homewood and South Chicago, is a most interesting one. Taking into consideration the large sum invested in coaches, $567 000, it would probably be judicious for this company to introduce motors of large power, capable of hauling the trains now used and under the same intervals of time. The steam locomotives could be used on other work of this system, and would not be a dead loss. The chief expense of installation would be the power plant, system of transmission and 33 combination baggage and motor cars, the total cost being not far from double that of the least estimate made by the electrical companies in 1891.

There is little difficulty in deciding the most economical methods of transmission for any locality after the ground has been gone over, the nature and amount of the service determined, and the cost to produce power at the central station figured. Where a great number of trains are run at frequent intervals, as on the Illinois Central, the conditions are especially favorable for the adoption of electricity. Almost perfect dynamos can be now furnished with an efficiency of 98 or 99 per cent. Very efficient slow-speed stationary engines can be had, and equally efficient electric motors. The chief problem is that of getting the current into the moving train. The objection to the overhead trolley is its unsightliness and obstructing the view of signals, and the third rail may be dangerous, although if a low voltage is used and only ordinary precautions taken, no danger need be anticipated.

Mr. Barrington

The advantages of electric traction for accommodation trains over comparatively short distances for suburban service around large cities, and to a certain extent for the transportation of freight, are very marked. A quick start, freedom from smoke and cinders, the slight expense of additional motor cars for extra equipment, all recommend it very highly.

Electric motor repairs cost infinitely less than those of steam locomotives, because the mechanism is far more simple. There are fewer moving parts, and these are not so much exposed to the action of mud, sand and water. More miles are run per day, or more hours of service are obtained per day, with electric motors than with steam locomotives, so that the cost of labor per mile is less with the former, and the amount of work done with a given sum invested is larger. When electric motors of large size and higher speed than those now used are made to take the place of locomotives, they will run about the same number of hours as the motors now in use, but will cover continuously from two and a half to three times the distance now covered by the locomotives. Locomotives must be run into the roundhouse and thoroughly examined and cleaned up more frequently. The electric motors used to move a train can be placed under one of the cars, so that the weight of the train is reduced and less power is required for moving it.

Operating figures secured from a number of large modern power houses recently range from $0.0075 to $0.0125 per kilowatt hour; these figures include the cost of coal, water, supplies, repairs and labor, but do not include taxes, insurance, interest or depreciation. Converting these figures into annual cost, it will be seen that they are equivalent, on the basis of twenty-hour service per day, to from $54 75 to $91 25 per kilowatt per annum, or from $41 to $68 per electrical horse-power per annum. Charles E. Emery, M. Am. Soc. C. E., in a discussion of the cost of producing power in 500 H.-P. units, made in 1893, showed that it could be delivered on the dynamo shaft of a direct-connected engine for $30 39 per horse-power per annum, with $2 coal; $38 45, with $3 coal; and $46 51, with $4 coal. Assuming a dynamo efficiency of 93%, these figures would become $32 70, $41 30 and $50 respectively, all based on a twenty-hour day for 365 days, and covering fuel, supplies, labor and repairs on engines alone. It seems, therefore, that there is an opportunity for electric railway plants to increase their economy, particularly in view of the fact that units larger than 500 H.-P. are usually found in most modern stations, and at least the labor account ought to be less than in Mr. Emery's assumed examples. To be sure, most stations work under disadvantages, such as inability to obtain condensing water, heavy cost of fuel, and enormous fluctuations in load, which prevent maximum engine economy from being reached.

There are some features of the single-acting compound engine

which it might be well to dwell upon, such as uniform economy over wide ranges of load, instantaneous regulation by inertia, limited space required, low cost of foundation, ease of attendance, ability to stand hard service under long-continued runs, and particularly low cost of maintenance and repairs, the latter being only 1.6% per annum of the cost. In the case of the Illinois Central installation, triple expansion engines of either 1 500 or 1 000 H.-P. each would probably be used. Mr. Barrington

Cleanliness in and about the power station will pay higher dividends than anything else connected with it, as misplaced tools and innumerable other articles will not have to be paid for, and the employees will take more interest where things are kept scrupulously clean and neat. In stations of over 2 000 H.-P. it will pay to extract the oil from old wipers. It is done by enclosing them in a tank into which a steam jet has been inserted. The oil on rising to the top can be drawn off for purification, the wipers dried out and used again, repeating the operation until they are worn out.

Iron or steel chimneys are advised, as they are cheaper and their factor of safety is ten, while that of brick chimneys is scarcely two.

Experience has proved that the total cost of repairs for rolling stock per car-mile averages about $0.017, divided as follows: Trucks, $0.002; motors, $0.005; bodies, $0.010. These figures include both labor and material, the latter costing about one-tenth more than the former. Repainting covers about 20% of the cost of repairs. By economies made in the car repair shop, such as carrying on all work on the piece system, these figures can be materially lowered. Results so far secured indicate a reduction of about 20 per cent.

It would be very interesting to know exactly what effect the electric and cable roads have had on the suburban receipts of the Illinois Central Railway during the last four years. Most steam roads have completely ignored this character of competition; in other cases it has been met by reduced rates and improved service, or the train service has been reduced and retrenchments made in other directions. In many localities, the increased inducements to travel afforded by the opening of rapid transit lines, and the improved facilities given by the old roads, have materially increased the traffic, so that it may be a question whether the net result has been altogether loss. The Illinois Central has refused to come down to a 5-cent fare, although the Northern Pacific gives a 20-mile ride for that amount. It is, undoubtedly, a fact, however, that the rapid transit surface roads are not only catching the short-haul passengers, but also many riding for long distances who find the surface roads more convenient for their purposes and now fast enough to use.

Charles Henry Davis, M. Am. Soc. C. E.—The paper is mostly of interest as history in the development of electric traction, showing clearly the truth of the author's words: "Engineers giving this matter Mr. Davis.

Mr. Davis. their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics," and, the writer would add, usually inexperienced as railroad engineers. In the growth of the electrical industry its greatest weakness has been displayed in mechanical design. The paper will be received with pleasure by those in the electrical business as another indication of the probable introduction of electric traction on parts of some of the larger steam railway lines. The use of electricity for suburban work on some steam railway systems is certain to come within a few years, but it will be adopted by conservative managers only when it can be shown to produce larger net receipts than steam locomotives. Higher operating expenses if accompanied with larger gross receipts might produce greater net results. One of the difficulties in the way is the necessity of discarding certain parts of the old system upon the cost of which interest must be paid, but this will be partly overcome by their use on other parts of the line which continue to be operated by steam locomotives. The writer will make some notes on the paper which are intended to bring out the unreliable nature of many of the answers, and the underlying causes affecting them, together with the many discrepancies and the wide divergence of opinions.

The author opens his paper by disclaiming any expert electrical knowledge, thereby inferring that such knowledge is requisite for a proper solution of the problem in hand. While the expert electrical engineer is a necessity for the best design and execution of part of such a change from steam locomotives to electricity, yet the engineering problems involved are much more those which can be best solved by sound mechanical and civil engineering as applied to transportation lines.

The method adopted by the author in studying the problem shows a clear judgment, and, it is hoped, will be repeated in his present investigations. Most of the questions are calculated to draw out desirable information, although many more could have been asked to advantage. The statement of conditions made to the electric companies is clear and concise, and sufficiently full for a preliminary study, and seems to have been understood by all, except as to whether 20 miles was the average or the maximum speed per hour. It was, undoubtedly, the former, although not so expressed by the use of the word "average."

The questions and answers will be discussed in detail and in consecutive order. The figures given are not always exact, but they will be found to be approximately correct and sufficiently so for the purposes of this discussion. The writer does not wish to be understood as attempting to belittle the labor and skill of those engineers connected with the large electric companies (many of whom are among the leaders in their profession), who have done so much for the permanent advance-

ment of the electrical industry, but wishes to give some idea of the methods, affiliations and other causes in the business which resulted in such widely divergent, inconsistent and inaccurate answers. Mr. Davis.

Question 1.—What capacity should motors have in horse-power?

Although the conditions of speed, load and character of track were given, the answers vary 100% from 100 H.-P. minimum to 200 H.-P. maximum, as follows:

(*a*)	150	H.-P.	divided	into	2	motors.
(*b*)	150–200	"	"	"	2	"
(*c*)	100	"	"	"	2	"
(*d*)	100	"	"	"	2 or 4	motors.
(*e*)	200	"	"	"	2	"

Undoubtedly one cause of the large variation in expressed horse-power is due to the fact that neither the question nor answers define what is meant by horse-power. It is quite possible that 150 H.-P. of one was only equivalent in capacity to 100 H.-P. of another. It is as necessary in determining the horse-power capacity of a motor to define its ampere current at a given electromotive force within a given heat limit, etc., as it is to define the steam pressure and speed, etc., of a steam engine before the horse-power can be intelligently determined. *d* undoubtedly advocated four motors, to increase the tractive effect, and because it was not until the latter part of 1892 that railway motors of over 30 H.-P. were in constant and successful operation for service of this character. It would therefore seem that each company was advocating the use of apparatus which was experimental. It is unnecessary here to go into the mathematics that would have accurately determined the necessary horse-power. *c* gave the lowest estimate of motor horse-power, a tendency it invariably had, and which, together with the lightness of its mechanical work, was a large element in the subsequent failure of the types designed by it. Although *d* made the same estimate of motor horse-power, at that time it underrated its apparatus, and the greater subdivision, recommended by this company, would have given a greater percentage of surplus power to call upon, if loads and speeds required it.

Question 2.—What will these motors cost? In giving cost, separate the cost of motors and motor cars.

Omitting the cost of bodies, which would largely depend upon their style and finish, and noting that *a* estimates on an electric locomotive and recommends its use, while the others advocate motor cars carrying passengers, it is found:

a	estimates	$8 000 for motors and trucks for locomotive.
b	"	7 000 for motor car without body (writer has deducted $1 000 for body, which assumes that trucks were estimated to cost $6 000; both figures and their sum obviously wide of the mark).

Mr. Davis.

c estimates $6 000 for motor car without the body and air brakes.
d " 5 000 for motor car complete without bodies.
e No estimate given.

The variation is from $5 000 to $8 000, or 60%; *a* does not state whether cab is included, while all but *c* are indefinite about brakes; this inexactness and the varying capacity in horse-power, together with the fact that, in most cases, new motors would have been built, caused the large difference in estimated costs.

Question 3.—Give approximate cost of trailers. Cars to be open cars, with cross seats, on first-class double trucks.

The answers are of no particular interest, as the cost, outside of electric light wiring and braking appliances, is dependent upon style, finish and local requirements, and entirely independent of the use of electric traction. Had the system contemplated been one where every car was a motor car, then the cost of electric connections, when running trains of two or more motor cars, would have needed careful consideration.

Question 4.—Is it desirable to have horse-power used for motor cars consolidated in one unit or divided into two?

The companies are unanimous in advocating a division of motor horse-power; all but *d* advise two units, it inclines toward four motors (see Question 1). *e* thinks that running two motors in series, enabling the use of 1 000 volts on the line, would be of advantage in saving three-fourths the weight of copper as compared with 500 volts. It would be interesting to know how this company proposed to operate and control the motors, and whether they had ever done it at this potential.

Question 5.—What is the best method to transmit the power of the motor to the axle, by gear or by crank?

a recommends gearless or geared motors.
b " gearless motors.
c " crank and parallel-rod connections.
d " single-reduction geared motors.
e " geared motors.

In the light of history it is interesting to study these recommendations and to speculate as to the causes influencing the statements of each company. The double-reduction geared motor had been used up to the first part of 1891, although the Wenstrom Company had advertised, and nominally placed upon the market, a single-reduction geared motor during the latter part of 1890. The S. R. G. motor of the Thomson-Houston Company was the first practical success in the single-reduction field, although the Wightman came out about the same time, as well as the Edison, and a little later the Westinghouse.

Mr. Davis.

About April, 1891, the Short and Westinghouse companies advertised the gearless motor, and in the fall of that year the writer had the opportunity, at Pittsburg, of testing a car equipped with Short gearless motors. The cost of building the gearless motor and the large current used by it when starting or running below speed were causes which lead to its abandonment, but recent developments and improvements point to its possible future use in certain fields of traction work. In 1889 the Edison General Electric Company was formed out of various allied interests, and in 1890 this company purchased the stock of the Sprague Electric Railway and Motor Company. In the same year the Thomson-Houston Electric Company purchased a controlling interest in the Brush Electric Company, thereby securing a majority of the stock of the Short Electric Railway Company. The absorption of the Sprague Company by the Edison resulted in the cancellation of territorial rights of the former's agents. These agents sought the Westinghouse Company, and it was mostly through this circumstance that the latter company became, at that time, active in the street railway field. The Thomson-Houston Company proposed to furnish its W. P. (water-proof) motors, which were then the best in the market and the least experimental; the Short Company, really the Thomson-Houston Company, so far as its proposal to the Illinois Central Railroad was concerned, offered a gearless motor, a few of which had been on the market about six months, although they were of much smaller size than those necessary for the proposed work, and even then it was seen that they would not be a success. This company was used by the Thomson-Houston Company to double its chances in competition. The Westinghouse Company was suggesting either gearless or single-reduction motors so as to cover the field; its railway department was then suffering from lack of experience and engineering ability in this particular line, the department being mostly dependent upon the experience of sales-agents from the Sprague Company, although some special engineering talent had also gone to it; these agents, however, secured an enormous business for their new associates. The Edison Company, through consolidations, constant changes of management and internal friction, which resulted in its absorption by the Thomson-Houston Company in May, 1892, had so demoralized its railway motor work as to have little of value to offer its customers. Its single-reduction motor was not a success, and the use of cranks and parallel rods for connections between motors and axles, which it recommended because of its recently acquired control of the Eickemeyer-Field methods, was a failure. The weakness of *e* is apparent from the meager information imparted in most of its replies.

Question 6.—What parts of motors are liable to give the most trouble from breakages, and what is the best and quickest method of handling motors that are disabled out on the line, and to avoid the least delays to traffic ?

Mr. Davis. *a* thinks that there will be no trouble from breakage; gears cause the most trouble according to *b*, although the burning out of fields and armatures may do so also; armatures and commutators cause the most trouble according to *c;* bearings and gears in the opinion of *d;* and gears in the experience of *e*. To get a disabled car in from the line it is variously suggested to use the unaffected motor, duplicate trolley wire and trolleys, and to push the stalled train by the next succeeding either to a siding of terminal; while *c* would, under some circumstances, quickly remove the connecting rods, presumably with the ease of steam locomotive practice "for the past 40 years." The answers indicate the general condition of the motors of each company. The Westinghouse Company, from lack of experience, did not know what parts caused the most trouble, therefore stated there would be none. The Short Company favored gearless motors, and therefore thought that gears would most frequently break. The Edison Company had, at that time, been troubled with burn-outs due to lightness of construction, high ratings and an attempt towards too great electrical efficiency at the sacrifice of repair account, resulting in great casualties to armatures and commutators where its motors were used, and therefore stated that these gave the most trouble. The Thomson-Houston Company had the greatest trouble with bearings and gears, for in its mechanical work it was weak as compared with its electrical work, the reverse being true with the Westinghouse Company at that time, and the Thomson-Houston Company therefore expressed its belief that these parts would need frequent renewals.

Question 7.—What is the best known brake for electric cars and motors suitable to the requirements of this line?

All the companies answered that the air brake operated by an electric motor on the motor car would give the best results; the writer cannot from memory state whether this had ever been done, but it certainly had not passed the experimental stage. The development to date is not what has been hoped for, there being room for future improvements.

Question 8.—What is the largest motor now manufactured, and where is it operated?

The answers show, as stated under Question 1, that 30 H.-P. was the largest railway motor then operated in passenger service, and that therefore each company proposed to furnish entirely new motors, except in the case of *d*, which proposed four motors of 25 H.-P.

Question 9.—In using two motors on a car it was understood that the motors work separately on both forward and rear trucks, and that the motor cars do not have to be turned at end of line.

Question 10.—Can both motors be used at once in the same direction, and can motors be reversed on line in an opposite direction, and can both motors be operated from same end of car?

Motor cars or electric locomotives were arranged at that time as now, so that motors could be run together or separately, reversed while running, operated together from either end of car, and the entire machine run in either direction ; the methods for accomplishing these results were very different and crude then as compared with those used to-day. Mr. Davis.

Question 11.—If the motor is designed for a speed of 20 miles an hour with a certain load, can the speed be increased with a less load without overstraining the motor and without any change in the mechanism, and what percentage can speed be increased?

All the companies answered in the affirmative; up to this time motors had been controlled by means of rheostats, except in the earlier experiments of Mr. Frank J. Sprague, who had advocated and successfully used series-parallel controllers. It was about the winter of 1891-92 that the various companies began using series-parallel controller stands which have since been developed to their present efficient and flexible modes of handling the motor equipments, enabling the motors to be run efficiently and satisfactorily at various ranges of speed, without jerking at the starting or intermediate points of acceleration, and without undue heating at any stage. What has been done in the past is likely to be surpassed in the future.

Question 12.—In how short a distance can trains described above be brought to a stop with existing brakes from a speed of 20 miles per hour ?

Except as to the feasibility of operating the air pump of the Westinghouse air brake system by an electric motor and the easy and quick reversal of the motors, the length in feet through which these trains could be stopped depended upon conditions which were entirely similar to steam railway practice. This question has been the subject of many elaborate articles with interesting tests, and is a matter outside the objects of this paper.

Question 13.—Upon the line under consideration, what would be the best location for the power house, taking into consideration that after the World's Fair the line will be extended 7 miles south, and that trains will have to stop at suburban stations at intervals of $\frac{1}{2}$ mile.

All but *b* and *e* took the view that the station should be located at the middle of the line; *b* thought that within 2 or 3 miles of this point would be safe to work in, while *c* was the only one which advocated a location nearer the end from which the extension was to be made; *c* and *d* thought an additional station desirable, after the World's Fair was over, each dividing the line into three parts. The answers to this question show how little thought was given to the problem by most of the companies. For the most economical distribution of electrical energy, the power house should, of course, be

Mr. Davis. located at the center of gravity (so to speak) of the units to be moved. This may or may not be the middle of the line. It is determined by treating the trains as weights located as they would be at the time of the heaviest travel. This factor is rarely, if ever, the limiting one in locating a power house. The question of available estate, delivery of coal, proximity of water, future growth and the like, are usually of more importance, while the center of gravity is more or less widely departed from. As the business from the World's Fair was only for a few months, it would have been cheaper, in the long run, to locate the power station or stations, irrespective of this factor. This would have made it necessary to put up additional temporary feeder lines and take them down when no longer necessary, rather than in the future labor under the disadvantage of a station much too large, if located at the right point, when an additional station was erected for the extension; or the disadvantage of a station poorly located, although large enough, should it alone be used when the line was extended.

Question 14.—How much power plant would be required to operate from sixty to seventy trains of 65 to 70 tons each at a speed of 20 miles per hour?

Question 15.—What excess power will be required in such a plant, if any?

Question 16.—What would you recommend as to the proper units into which this power should be divided?

Question 17.—If the requirements for power should be reduced 50% after the World's Fair, what power of each unit would you recommend?

Answers were as follows:

	Horse-power, Question 14.	Excess horse-power.	Total horse-power.	Horse-Power of each unit.		Total horse-power of trains (70).	Difference in horse-power.
				Dynamo.	Engine.		
(*a*).....	4 800	8 000	12 800	800	800	10 500	+2 300
(*b*).....	8 000	2 000	10 000	500	1 000	10 500	— 500
(*c*).....	5 000	.....	5 000	400	400	7 000	−2 000
(*d*).....	4 000	1 000	5 000	500	500	7 000	−2 000
(*e*).....	12 500	2 500	15 000	750	1 500	14 000	+1 000

Why *a* should desire 166% additional capacity as spare machinery is hard to understand except on the score of ignorance or unreliable apparatus. It is also hard to see the advantage of two generators direct-connected to one engine as in the case of *b*; no one would think of one 1 000 H.-P. dynamo driven by two 500 H.-P. engines on the ground that "one engine (dynamo) might break down." *c*, as was its usual tendency, estimated on a low capacity with no surplus; *d* was below *c*, which was unusual with this company, as it too often installed apparatus entirely too large for economical work; this, however,

could be explained by its desire to make a low bid. The following vari- Mr. Davis.
ations between highest and lowest are interesting.

1. Horse-power, Question 14 ..... 212%
2. Excess horse-power 700%
3. Total horse-power 200%
4. Horse-power of each unit (dynamos) 100%
5. " " " (engines) 275%
6. Total horse-power of trains 100%
7. Difference in horse-power (total horse-power in station and total in trains) 215%

Such variations are astonishing when one realizes that even at that time the efficiency of boilers, engines, generators, line and motors was known with reasonable accuracy, even if parts of the system were uneconomical when compared with apparatus of to-day. There is no doubt that a large part of the variation was due to inaccuracy in the estimated horse-power required per train, and to the element of judgment in estimating the maximum station load and a desirable surplus.

Question 18.—How many square feet in space will be required for the erection of steam and electric power plant, including boiler house?

Question 19.—Give your opinion as to the most economical and best kind of boilers, engines and generators to use for such a plant.

Question 20.—Give approximate cost of power plant, to erect engines, boilers, generators, separately.

Question 38.—Do you recommend horizontal or upright engines?

Question 39.—What is the best form of connection between engines and generators, belts or countershaft?

Question 40.—Are high or low speeds preferable, and about how many revolutions per minute?

The following variations in area required depend upon the peculiar design of steam plant recommended by each company, such as whether generators were belted or direct-connected:

	Square Feet Ground.		Boilers.	Engines.	Generators.
	One story.	Two stories.			
(*a*)...	75 000	.....	B. & W.	Corliss, 300 revs.	Westinghouse.
(*b*)...	43 750	21 875	Water-tube.	Horizontal Corliss, 100 revs.	Direct-connected.
(*c*)...	15-25 000	12 000	" "	Horizontal compound, condensing medium speed, 100 revs.	" "
(*d*)...	25 375	.....	B. & W.	Compound or triple-expansion, 100 revs.	" "
(*e*)...	27 300	.....	Climax.	Vertical triple condensing Corliss, 100 revs.	" "

Mr. Davis. It will be seen that in each case the following space per horse-power has been allowed:

	Square Feet Ground.		Horse-power.	Square feet per horse-power.
	One story.	Two stories.		
(*a*).....	75 000	.....	12 800	5.85
(*b*).....	43 750	21 875	10 000	4.37
(*c*).....	15–25 000	12 000	5 000	3.00–5.00
(*d*).....	25 375	.....	5 000	5.07
(*e*).....	27 300	.....	15 000	1.80

a intended to use belted or rope-driven apparatus without shafting. *e* saved space by the use of vertical boilers and engines; unless ample boiler power were furnished so as not to force them when in use and good water were obtainable, the use of vertical boilers would have proved undesirable. The estimates of cost for power plant with building complete, but without real estate, are as follows:

	Cost.	Horse-power.	Per Horse-Power.			
			Steam plant.	Electric plant.	Building.	Total.
(*a*).....	$475 000	12 800	.....	.....	.....	$37
(*b*).....	1 000 000	10 000	$55 (?)	$35 (?)	$10 (?)	100
(*c*).....	320 000	5 000	40	24	.....	64*
(*d*).....	455 000	5 000	46	35	10	91
(*e*).....	1 169 000	15 000	.....	.....	.....	78

* Without building.

These total costs vary 216%, if $10 per horse-power is added as in other cases for buildings, not included in *c*'s estimate, and the variation is 170% in cost per horse-power, or 35% if the Westinghouse belted apparatus is omitted. When it is considered that these are estimates upon plants which have neither been located nor designed, a variation of 35% in the cost per horse-power on the same type of machinery is not unreasonable; the variation in the aggregate cost is mostly due to the 200% variation in the amount of horse-power recommended as necessary.

Question 21.—Give estimated cost for operating power plant, with coal at $1 per ton.

Question 30.—How much will it cost to operate this system per mile, per motor and per car, and also per passenger per mile?

Without repeating details the various estimates were:

Mr. Davis.

	Hours run.	Average horse-power.	Total horse-power.	Operating Cost per Year.	
				Total.	Per average horse-power.
(*a*)	..	....	12 800	$60 000	....
(*b*)	18	7 500	10 000	225 000	$30
(*c*)	18	Coal and labor only.	5 000	52 560	....
(*d*)	18	2 666	5 000	96 794	36
(*e*)	18*	Depreciation and repairs omitted.	15 000	222 650	....

* In the case of *e* the figures have been interpolated from 12 hours to 18 hours per day, adding $190 per day for the additional time.

Again the variation in operating expenses is due to the large differences in the estimated average power required.

The Thomson-Houston Company gives the cost of motive power as follows per car-mile: Station, 0.0069 cent; line, 0.0005 cent; motors, 0.0088 cent; total, 0.0162 cent.

a estimates cost of operating per locomotive-mile. 9–10 cents.
b " " " " car-mile..... 12.5 cents.
d " " " " " at..... 0.0112 cent.

The above strongly indicates the unreliable and inaccurate nature of the data given; *a* does not make it clear what part of the question is answered; *b* is the only clearly stated answer; while *c* and *e* do not reply, and *d* gives 0.0112 cent as the cost per car-mile, which, however, only includes station power and line transmission.

Question 23.—What is the best method of transmitting power from power house to motors?

Question 24.—If by the use of conduit, give estimated cost. If by the three-rail system, give cost. If by the overhead trolley system, give cost.

Question 25.—If the overhead trolley system is used, what is the best method for supporting wire, and how far should the supports be apart?

Question 26.—(1) What size should trolley wire be? (2) What size should feed wires be, and what distance apart should they feed into the trolley wire? (3) Give probable cost of repairs and maintenance of three systems.

Question 42.—What will be the percentage of loss in power between the steam engine and the motor?

The companies were unanimous in recommending the overhead trolley. It would be interesting to see what views they would express to-day, based upon experience in the use of a third rail on elevated systems, underground conduit work on surface street roads, the failure of special trolley work on the New York, New Haven and Hartford

Mr. Davis. Railroad, and the latter's only moderately successful use of the third rail on tracks which are not elevated.

a makes the total efficiency about ..... 57.5 per cent.
b " " " ..... 51.1 "
c " " " ..... 63.7 "

(According to figures, although total is stated at 50 per cent.)

e makes the total efficiency about..... 85.0 cents.

The estimated costs vary even more than other figures given. They are tabulated below, some of the amounts having been calculated from data given in answer to other questions :

	Cost of				Number of trains.	Kind of work.
	Overhead line.	Feeders.	Rail return.	Total.		
(*a*).....	.....	.....	.....	150 000	40	Wooden center pole.
(*b*).....	19 000 22 000	112 000 150 000	.....	131 000 172 000	50	" " "
(*c*).....	10 000	75 000	37 500	122 500	..	" " "
(*d*).....	.....	6 039	.....	40 000	40	" " "

	Size of trolley wire.	Feeders tap in every	Repairs.	Loss in line.
(*a*).....	00	2 640 ft.	None.....	20 per cent.
(*b*).....	00-000	500 "	5 per cent. of cost	15 "
(*c*).....	0000	100 "	.....	18 "
(*d*).....	00	....	9.5 per cent. of cost.....	20 "
(*e*).....	.....	500 ft.	3 per cent. of cost	7.5 "

Rail return work was apparently not included, except in one case, so that, should it be added to the other figures, at the estimated cost as given by *c*, there is a variation of 423% in total cost, and 166% in loss in line. Taking two-braid weather-proof 0000 wire weighing 671 lbs. per 1 000 ft., and 15 cents per pound as the price of wire at that time, and cost of stringing, cross-arms, insulators, etc., at 1 cent a pound (approximate), *b* must have estimated on about the equivalent of 1 596 000 ft. of 0000 wire, while *d* proposed using only 60 000 ft. of the same size wire. Had *b* obtained an average loss of 15% with the amount of copper proposed, 1 071 428 lbs., what would *d* have obtained with only 40 260 lbs.? *b* was figuring on 25% more trains. The average horse-power per train is given by *b* as 100 in the answer to this question, and 170 in the answer to Questions 18, 19 and 20. *d* gives it as 66.5 H.-P. The former recommended 150 to 200 H.-P. per car as equipment. and the latter, 100 H.-P. Assuming 100

H.-P. as correct, in the first case, *b* estimated on 50% more power per train than *d*. The loss in line, in this case, would be directly as the power, and, if the loss is doubled, the weight of copper is reduced to one-quarter; therefore *d*, assuming that *b* has estimated the loss correctly, seems to have figured on a drop of about 30%, although stating it to be only 20% (remembering that *b* proposes one power house, and *d* two, therefore halving the feeding distance in the latter case). Other discrepancies appear in the answers. *a* expresses the opinion that it costs nothing to maintain line work, while *e* has little to say on the subject. Mr. Davis.

Question 31.—Is there any electric line in operation similar to the one under consideration?

As stated in the answers, there were none; nor are there any to-day, although some of those at present in operation more nearly approach the conditions of the Illinois Central Railroad. In the year 1892 the first serious attempts were made to build cross-country trolley roads of high speed, operating on schedule times similar to steam railways. Among the first of these, designed and built by the writer as chief engineer, was the Washington, Alexandria and Mount Vernon Electric Railway, about 10.5 miles long, upon which was made a time of 22 minutes from terminal to terminal, or about an average of 35 miles an hour exclusive of stops. This was done with single-reduction double W. P. 50 Thomson-Houston Company motors, double-truck 34-ft. cars pulling one trailer of similar size. The generators were two 150 kilowatt bi-polar, Edison type, belt driven by Greene condensing engines, and steam was furnished by return tubular boilers. In the operation of this system the writer tested a single motor car with and without a trailer. Without giving the details, a train often took over 200 amperes (134 H.-P. at 500 volts) for a time, while the maximum loads never exceeded 67 000 lbs., and the speed with this load about 20 miles per hour. This road could not be compared with the problem under discussion, but these figures indicate that the motor equipments proposed would not have done the work required of them.

Question 34.—Is it possible and practicable to carry from 20 000 to 30 000 passengers per hour with electric power under the conditions named?

Question 35.—Is it possible and practicable to equip and install this plant, ready for full and complete operation, by March 1st, 1893?

Question 36.—How soon will it be necessary to award the contract for the above plant in order to have the line ready for operation by March 1st, 1893?

Question 37.—Would your company guarantee, on your own specifications and at an agreed price, the successful installation and operation of this plant by March 1st, 1893, with guaranteed capacity of 20 000 people per hour in one direction?

Mr. Davis. These were all answered in the affirmative except the last question, answers to which were omitted by *c* and *e*. The daring and enterprise of the electric companies was surprising when it is considered that what they proposed to undertake was to design and build motors, trucks or motor connections to existing standard trucks, generators and the hundred and one modifications in existing devices of switchboards, wiring, etc. However, an analysis of the data given by them evidently could not have encouraged the engineering department of the Illinois Central Railroad Company to make the change.

Question 41.—What is the proper size of wheels for motors and for trailers?

a recommends 42 in. for motor cars; 33 in. for trailers.
b " 42 " " " 33 " "
c " 30 " " " 30 " "
e " 48 " " " 48 " "

	Circumference of wheel in feet.	Axle Revolutions Per Minute at Given Miles Per Hour.				
		20	30	35	40	50 miles per hour, or
		1 760	2 640	3 080	3 520	4 400 ft. per minute.
		22.5	15.0	12.8	11.25	9.0 { Express time, minutes, Van Buren St. to World's Fair.
(*a*).....	11	160	240	280	320	400
(*b*).....	11	160	240	280	320	400
(*c*).....	7.8	225	337	393	450	562
(*e*).....	12.5	140	210	245	280	350

At the time of the World's Fair the average time from Van Buren Street to the exposition grounds was 12 minutes, or an average of about 37.5 miles per hour for express service. This would indicate that at times nearly 50 miles per hour was attained by steam locomotives performing this service, so that the entire electrical equipment proposed at that time would have been much too light to perform the actual work done later by steam.

The axle speeds are given in the table. If the ratio was four between armature and axle, low for motors at that time, the motor speed would have been such that those proposed could not have maintained the required train speeds.

The preceding analysis of the answers leads to the following main conclusions:

A large part of the apparatus would have been built new. As the design of electrical appliances is, even to-day, more largely experimental than in almost any other branch of engineering, it was unlikely that the attempt would have been highly successful.

Estimates of initial costs and of operation were only approximate and evidently very inaccurate. Mr. Davis.

The motor equipments proposed would not have been able to handle the express service to the exposition grounds.

The adoption of electric traction would have resulted in loss of business due to slowness of trains as compared to what was done with steam locomotives.

Although the change would undoubtedly have been made in time and the road would have operated and carried an enormous number of passengers, yet the net results would have been a failure, so far as the Illinois Central Railroad Company was concerned.

JOHN FINDLEY WALLACE, M. Am. Soc. C. E.—The discussion of this paper has been rather along general than specific lines, presumably because few installations of electric power even approaching so heavy a service as is required by the suburban traffic of the Illinois Central Railroad are in operation. As illustrating the service of the Illinois Central Railroad in comparison with that of two electric elevated roads, the accompanying speed diagrams (Fig. 4) are submitted. In the case of the Illinois Central, the total train-load was 260 000 lbs.; in that of the Metropolitan Elevated, the load was 100 000 lbs., and in that of the Lake Street Elevated the load was 120 000 lbs. It will thus be seen that the Illinois Central suburban service is much heavier than that of the other roads exemplified, both as to weight of train and speed attained. A study of these diagrams will develop the advantage of reduction of dead load hauled as compared with load of passengers, which at best is but a small fraction of the total. This reduction of dead load seems to be one of the principal advantages of traction by electric power. To attain the speed required by the Illinois Central schedule, the power applied to the hauling of the elevated train illustrated would require to be considerably increased, taking into account both the elements of maximum speed attained and the distances between stops. Mr. Wallace.

The powerful character of the suburban engines of the Illinois Central is indicated by the data given in the paper, and the speed diagrams show that these engines are being worked to their full capacity, and of necessity beyond their maximum economy in the production of power. The fuel consumption runs something over 90 lbs. of Illinois coal per train-mile.

The increase of the number of trains involved in changing the present system of heavy trains to that of one, two or three car trains, including motor cars, introduces the question of allowable speed under short headways. Powerful motors would naturally be required in order to accelerate quickly, so making any schedule called for with the least expenditure of energy. Fig. 5 shows the maximum speeds required to be attained for different distances of

Mr. Wallace.

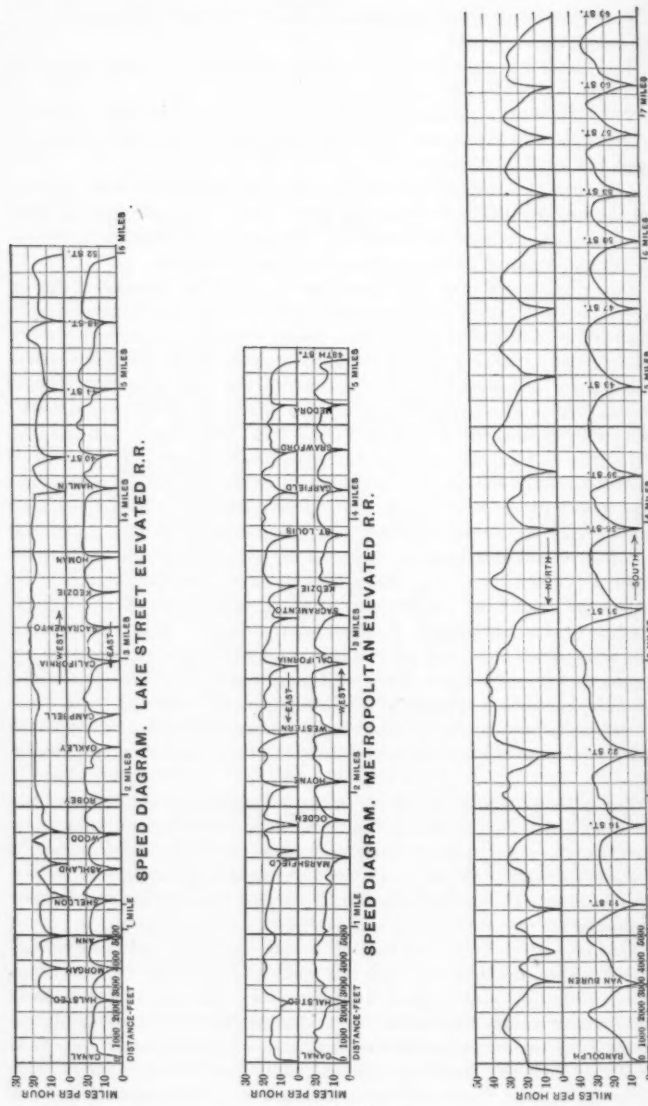

FIG. 4.

acceleration and retardation between stops for various time schedules between Randolph and Sixty-third Streets, the limits of the local suburban service as distinguished from the express. It will be noticed by examination of the diagram that the principle of quick acceleration involving less expenditure of total energy is well illustrated, see- Mr. Wallace.

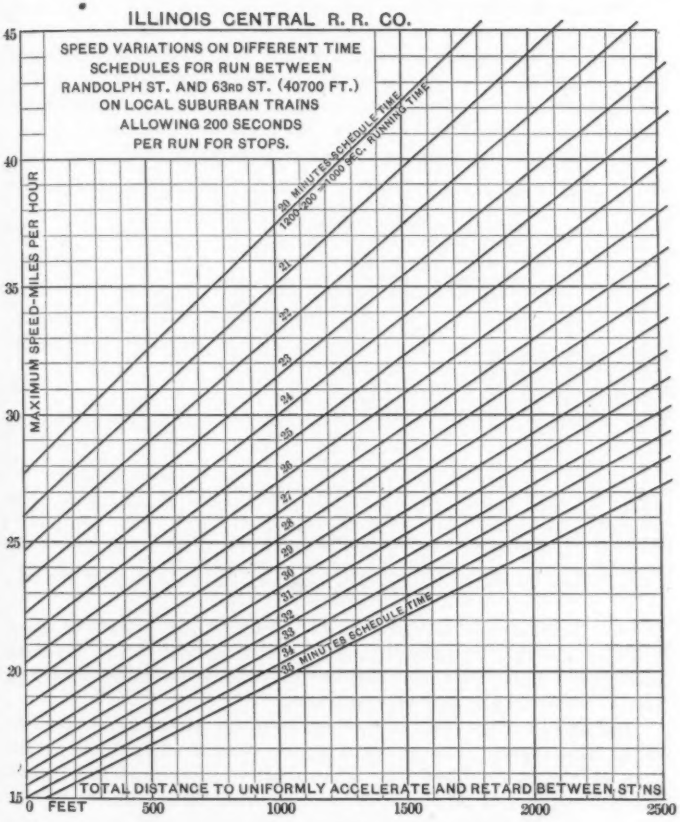

FIG. 5.

ing that total energy of acceleration varies approximately as the square of the maximum speed attained.

It is somewhat curious to note in the discussion of this paper the following diametrically opposed opinions:

Mr. Wallace.

Mr. Clarke: "To make a city elevated railway a success, the surface elevated system must be copied and not the steam locomotive system of long trains at greater intervals."

Mr. Knight: "The direction in which progress lies is apparently in the line of larger trains moving more rapidly. The whole object of the elevated railway is speed, and speed cannot be had with short headways."

Perhaps the best reason which might be given for this difference of opinion is that each was considering different conditions of train-loading. One evidently had in mind a uniform loading, and the other was considering the exigencies of the morning and evening rush. Fig. 6 illustrates the conditions holding on the Illinois Central local suburban service during an average day; the maximum number of passengers carried per minute on the peak of the evening load being called

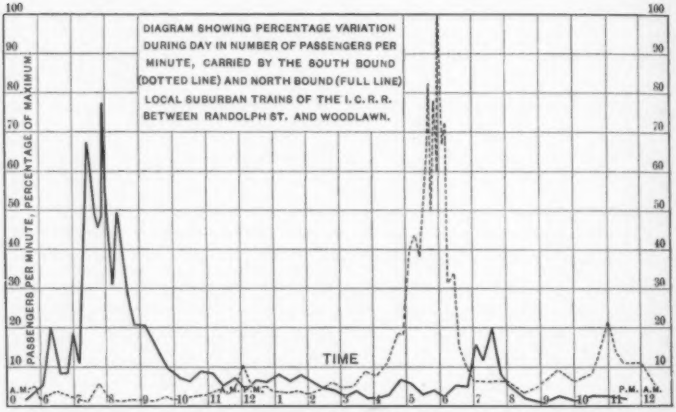
DIAGRAM SHOWING PERCENTAGE VARIATION DURING DAY IN NUMBER OF PASSENGERS PER MINUTE, CARRIED BY THE SOUTH BOUND (DOTTED LINE) AND NORTH BOUND (FULL LINE) LOCAL SUBURBAN TRAINS OF THE I. C. R. R. BETWEEN RANDOLPH ST. AND WOODLAWN.
PASSENGERS PER MINUTE, PERCENTAGE OF MAXIMUM
TIME
A.M.
P.M.
A.M.

FIG. 6.

100 for convenience, and the number carried per minute at other times of the day being indicated by a percentage of this assumed maximum. Figs. 7, 8 and 9 indicate the number of cars per hour in service on both local and express trains.

Taking care of the peak of the load is of the utmost importance, as in the morning and evening rapid transit is more urgently called for than at any other time. The heavy draft of power and the violent fluctuations of load on the power house during the evening peak constitute one of the main difficulties to be contended with in an electric installation, as much of the machinery generating power at that time is idle during the greater part of the day. Whether the storage battery will solve the difficulty or not is more or less a matter of speculation so far as a service such as that of the Illinois Central is concerned.

Mr. Wallace.

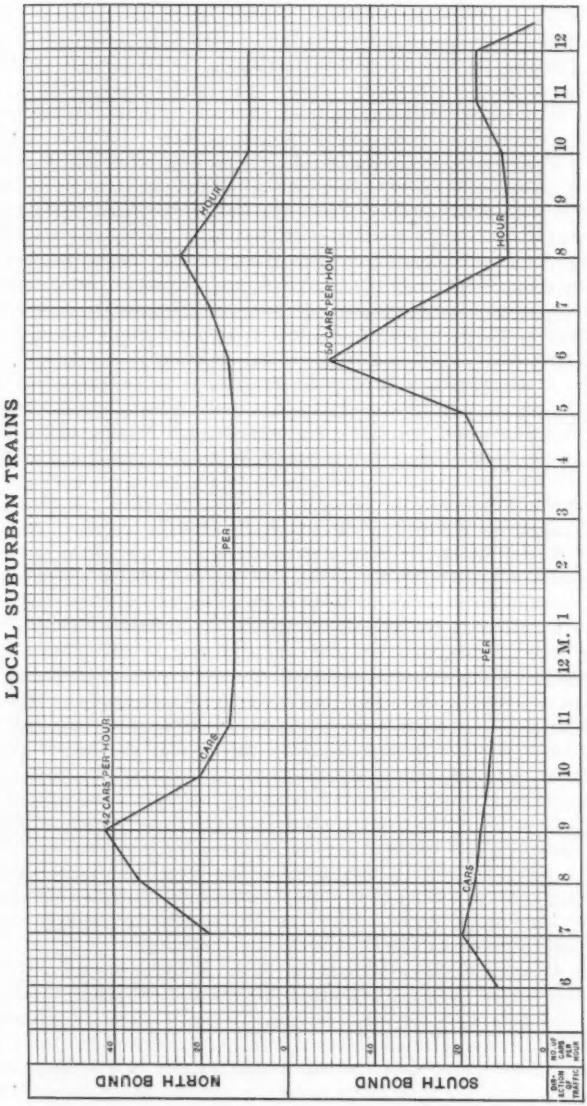

FIG. 7.

Mr. Wallace

The wide differences of opinion among electrical experts as to the cost of an electrical application at the present time as well as in 1892 is due largely to the differences in their ideas as to the details of power and speed requirements. Slow speed and a greater distance in which acceleration is permissible in order to obtain the maximum speed, are important factors in the matter of cost.

Mr. Clarke says: "The author should have added that the electric system is better adapted to frequent stops, and the steam locomotive to stops far apart." This is not necessarily the case. While it is true, as the author has heretofore stated, that the electric system is adapted to small units of transportation moved at frequent intervals, and the steam locomotive is adapted to large units of transportation moved at less frequent intervals, it does not necessarily follow that the electric system is better adapted to frequent stops inside of certain limits.

The author does not agree with Mr. Clarke in his statement that the tendency in the future of city elevated railways will be towards light structures, carrying light and very frequent trains, with motors on the cars themselves, for the reason, as he previously stated, that the preference for elevated roads shown by the public is only due to the increased speed of the latter over the surface lines, and increased speed cannot be obtained on elevated roads with the lighter equipment which Mr. Clarke has in view, particularly on account of the fact that the greater volume of traffic on lines of this character is concentrated within comparatively short periods of time, and the maximum number of people cannot be handled during these busy hours with small, frequent units of transportation. On the contrary, it will be necessary, especially if the business increases still further, to enlarge the size of the units as well as their frequency, to provide for a safe headway between trains in order that they may be run at greater speeds than now, at the same time enabling them to carry the greater number of people within the minimum period of time.

The author, however, thoroughly agrees with Mr. Clarke when he says that the main advantage of electric motive power is the fact that it will provide more frequent service at those hours of the day when travel is light, in order to stimulate business by giving increased convenience, and the ability to do away entirely with regular schedules for the running of trains. This remark applies particularly to the conditions existing on the Illinois Central Railroad.

The economy of the system is due to the fact that electric traction costs less per unit where it is desired that the units be small, than does steam locomotion for the same service. While it is true that traction is a very important element, the weight of powerful electric motors increases in such proportion that additional traction is also furnished. The author does not wish to be understood as favoring electric loco-

Mr. Wallace.

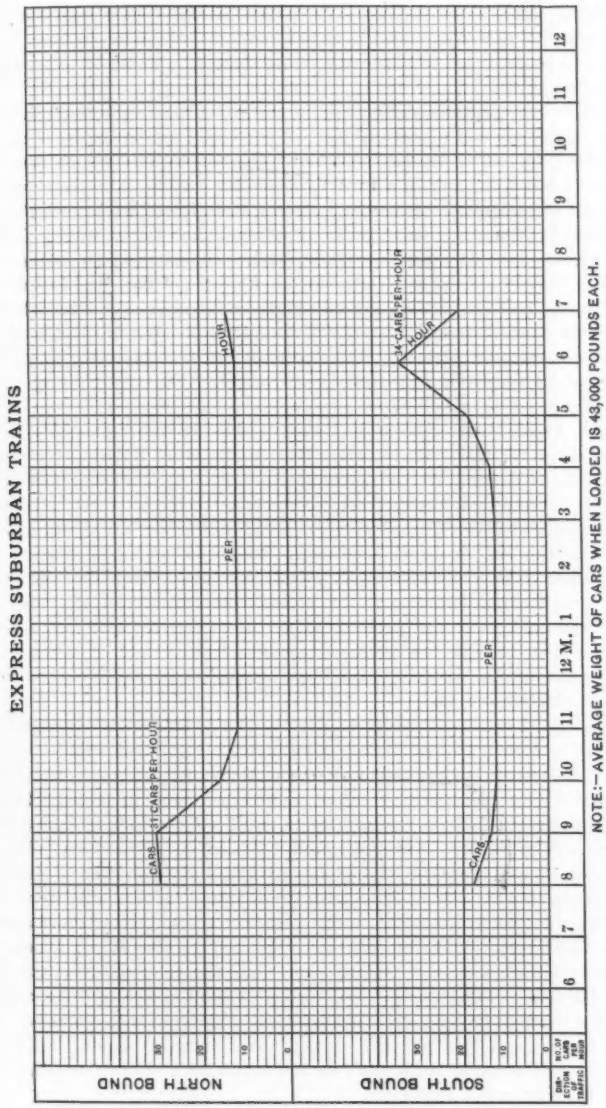

FIG. 8.

Mr. Wallace. motives, but his investigations so far incline him to prefer motor cars of sufficient power and weight to haul trailers; these motor cars, however, to be provided with the maximum seating capacity for passengers possible.

One of the practical difficulties in the way of placing motors on each axle of the car and on several cars of the train, and coupling them up so that they can all be used and under the control of one motorman, is that, so far as the author's investigations have gone, there is as yet no perfect and adequate controller in use in the United States which will provide for the proper manipulation of more than two motors. In the recent inquiries which he has made, he has endeavored to find a controller that would operate four motors under one car, that is, one on each axle; and found that the two-motor controller was virtually the limit of present practice in the United States. While electric companies claim to have controllers to operate four motors on the axles, the motors are only two two-motor controllers. This problem has evidently not yet been solved.

Mr. Prout states that it is "improbable, in the light of present knowledge of the subject, that the traffic now handled by steam traction, if carried in the same manner and at the same intervals, could be handled cheaper by electricity." He is correct in this statement. In the Illinois Central local suburban application over that portion of its service between Randolph and 63d Streets, it developed that a comparatively small economy would result from the substitution of electric for steam locomotives on the present schedule and with the present units of transportation, but it was shown that to give the frequent service desired and contemplated under the electric application, a large saving would be effected by the use of electric power.

In regard to his statement relative to the difference of opinion between the former and present general managers of the Manhattan Elevated Railway as to the economy of the electric application, the mere fact that two gentlemen of such wide experience in transportation matters should differ in opinion is in itself satisfactory evidence that electrical engineers have yet much to learn in regard to railroad conditions, and that their statements are based more on their individual beliefs as to what can be done than upon actual facts and figures.

Since the paper was written, the author has been giving close attention to the study of this problem as applied to the Illinois Central local suburban service. It has been found that the requirements on the Illinois Central as to speed and acceleration are approximately double those of any practical application of electricity to a similar service to-day, and that the principal electric companies are, to a large extent, still groping in the dark as to the proper and economical solution of problems of this kind.

Mr. Wallace.

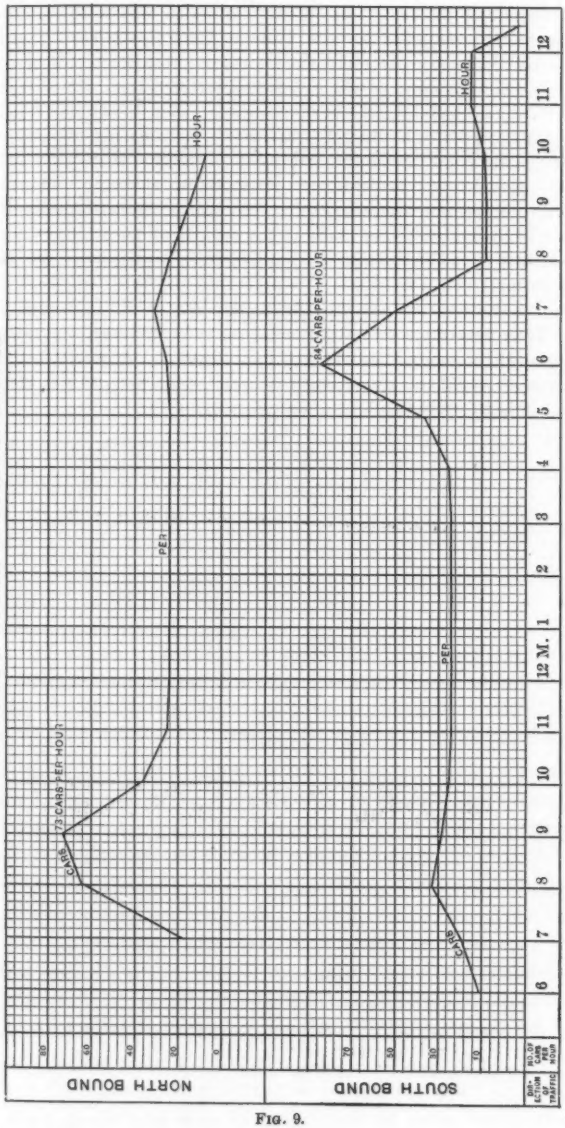
EXPRESS & LOCAL SUBURBAN TRAINS
NORTH BOUND
SOUTH BOUND
73 CARS PER HOUR
84 CARS PER HOUR
NOTE: AVERAGE WEIGHT OF CARS WHEN LOADED IS 43,000 POUNDS EACH.

FIG. 9.

Mr. Wallace. It may be of interest to know the manner in which this investigation is being conducted by the Illinois Central Railroad Company. The matter has been placed by the management in the hands of an advisory board consisting of the general superintendent, the chief engineer and the superintendent of machinery. This board has employed John Lundie, M. Am. Soc. C. E., as an engineering secretary and expert, with proper assistants, to carry on the investigations and examinations and report to the board. Every detail of the problem is being carefully looked into and analyzed. The substitution of electricity for steam will undoubtedly be made if the results of these investigations demonstrate that the electric service will be as economical and efficient as the present steam service. The principal object of the change is to secure a more frequent service during the hours of light traffic, if it can be done without materially increasing the expense of operation, in the hope that thereby business will be increased. A minor object is, of course, to avoid the annoyance of smoke and steam, as the line runs through a high-class residence portion of the city.